PB-217 920

WATER QUALITY AND POLLUTION CONTROL STUDY. MINE DRAINAGE - CHESAPEAKE BAY, POTOMAC RIVER BASIN, SUSQUEHANNA RIVER BASIN, AND DELAWARE RIVER BASIN

Federal Water Pollution Control Administration
Charlottesville, Virginia

July 1967

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WATER QUALITY
AND
POLLUTION CONTROL STUDY

MINE DRAINAGE
CHESAPEAKE BAY — DELAWARE RIVER BASINS

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CB-SRBP Working Document No. 3
FWPCA
Middle Atlantic Region
July 1967

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I. PURPOSE AND SCOPE

The purpose of this report is to provide background information to be used in the development of a program to eliminate or reduce the effects of mine drainage pollution on the quality of the streams in the Susquehanna River, Delaware River, and Potomac River Drainage Basins. The report covers both the anthracite and bituminous coal mining areas in these Basins.

The ~~principal~~ objectives of the report ~~are to:~~ does the following:-

1. Generally describe the chemical and physical processes involved in the formation and occurrence of mine drainage pollution,
2. Identify and characterize the watersheds contributing mine drainage,
3. Relate mine drainage contributions of the tributaries to the main stem of the receiving stream,
4. Isolate and identify significant discharges in terms of quality and quantity.
5. Identify and estimate the extent of areas disturbed by mining operations, for control, and estimate costs,
6. Suggest measures to be taken to abate or alleviate the effects of mine drainage pollution in specific sub-basins.

7. Estimate costs of mine drainage pollution abatement and control.

All conclusions, recommendations, and estimates contained in this report are subject to further refinement as the program of the Chesapeake Bay-Susquehanna River Basins Project progresses.

II. SUMMARY AND CONCLUSIONS

A. Summary

1. The Chesapeake Bay-Susquehanna River Basins Project is engaged in a comprehensive water pollution control study in a portion of the area covered by this report. Studies to determine the source of mine drainage pollution and the estimated cost of abatement have been carried out and are continuing.
2. Preliminary data have been compiled relative to the extent, causes and abatement of mine drainage pollution in the Susquehanna, Delaware, and Potomac River Basins. Studies to be conducted in 1967 are expected to supplement data collected to date, making possible more refined estimates concerning the extent of mine drainage pollution in the Study Area and appropriate abatement measures.
3. For the purpose of this report, the Study Area has been subdivided into sub-areas: The West Branch Susquehanna River Basin, the Juniata River Basin, the Tioga River Basin, the Susquehanna River Basin Anthracite Area, the Delaware River Basin Anthracite Area, and the Potomac River Basin.
4. Mine drainage has rendered approximately 1,000 miles of streams in the Study Area acid. The quality of

another 1,000 miles of streams is degraded by other mine drainage constituents and by intermittent influence of mine drainage on streams or portions of streams not usually significantly affected by mine drainage.

5. An estimated 5,000 mining operations have been active in the bituminous coal fields in the period 1800 to the present, producing about 1 billion tons of coal. An estimated 1,000 major mining operations in the anthracite coal fields produced 5 billion tons of coal.
6. Of the 679 major mine drainage discharges located in the Pennsylvania portion of the Study Area of the Chesapeake Bay-Susquehanna River Basins Project, 188, or 28 per cent, were found to be contributing 90 per cent of the acid loading. Comparable data are not presently available for the Potomac River Basin portion of the Study Area.
7. Restoration of the 208,500 acres of the Study Area disturbed by surface mining will cost on the order of $273 million.
8. The estimated cost of lime neutralization of residual mine drainage loadings not abatable by land reclamation methods will range from $258 to $983 million. Estimates

are based on construction and 10 years of operation of treatment facilities.

9. Restoration of the quality of streams presently polluted by mine drainage to a level consistent with quality required for desired water uses is estimated to range in cost from $531 to $1,256 million.

B. Conclusions

1. Sub-basins have been identified in which mine drainage pollution abatement appears to be attainable with a comparatively small expenditure of time and money as compared to the remaining sub-basins in the Study Area. These sub-basins should be considered for highest priority in any limited mine drainage pollution abatement program. These sub-basins are:

    a. Anderson Creek - West Branch Susquehanna River Basin

    b. Loyalsock Creek - West Branch Susquehanna River Basin

    c. North Bald Eagle Creek - West Branch Susquehanna River Basin

    d. Tioga River - Chemung River Basin

    e. Little Juniata River - Juniata River Basin

    f. Frankstown Branch Juniata River - Juniata River Basin

g. Aughwick Creek - Juniata River Basin
h. Nescopeck Creek - Susquehanna River Basin
i. Mahantango Creek - Susquehanna River Basin
j. Lehigh River - Delaware River Basin
k. Abram Creek - Potomac River Basin
l. Elk Run - Potomac River Basin
m. Laurel Run - Potomac River Basin (Maryland)

2. Coal production is expected to continue throughout most of the Study Area. Existing water pollution control authority in Pennsylvania is adequate within the limits of economic and technical feasibility to essentially prevent additional stream quality degradation in conjunction with future mining. Present regulatory authority in Maryland and West Virginia appears to offer much less restriction to pollution caused by future mining.
3. State regulatory agencies and the mining industry have done considerable work in determining and applying methods of abating and controlling mine drainage pollution from both active and abandoned mines. Funds are not presently available at the State level to undertake the costly program of mine drainage pollution abatement from both active and inactive mines on a comprehensive basis. A bond

issue, recently approved in Pennsylvania, will make approximately $200 million available for mine drainage pollution abatement and control activities over a 10-year period.

4. Reclamation of land disturbed by surface mining is needed to restore its utility. This activity, coupled with mine flooding, restoration of surface drainage disturbed by subsidence, and other activities aimed at altering existing drainage patterns will reduce mine drainage contributions to the streams of the Basin. It is doubtful that such work alone will completely abate mine drainage pollution. Mine drainage treatment facilities and/or flow regulation for water quality control will be needed in some areas. Additional studies are needed to evaluate the most feasible approach to mine drainage pollution control in individual sub-basins.

III. INTRODUCTION

Mine drainage has been defined by the Susquehanna River Basin Study Mine Drainage Work Group as any "discharge influenced by or originating from surface or underground mining operations and natural discharges which by the nature of their chemical or mineral characteristics exert detrimental effects on the receiving environment.

Although mine drainage does occur in the natural process and from the mining of many mineral deposits, by far the most serious mine drainage pollution problem in the Study Area results from the commercial mining of coal. The areal distribution of the major coal fields within the area of responsibility of the Chesapeake Bay-Susquehanna River Basins Project (CB-SRBP) is shown on Figure 1.

An estimate of the area containing coal and allied deposits in the Study Area is as follows:

Anthracite -	Northern, Western Middle, Eastern Middle, and Southern Fields	529 sq. miles
Semi-Anthracite -	Mehoopany, Towanda, Pine, and Loyalsock Creek Basins	55 sq. miles
Bituminous -	Broad Top-Juniata Basin	81 sq. miles
	West Branch Susquehanna River Basin	3,606 sq. miles
	Tioga River Basin	59 sq. miles
	North Branch Potomac River Basin.	370 sq. miles

Water pollution problems associated with mine drainage are not new. Discharges flowing from mineral deposits through natural faults and fissures have, undoubtedly, always possessed mine drainage characteristics. Long before the first commercial coal mine was opened, the Indians of the area were aware of the "black stone" that burned. They used the many hued mud deposits of early mine drainage streams as a source of pigments and dyes.

Although mine drainage occurs naturally, the growth of the commercial coal mining industry has greatly accelerated the production of mine drainage discharges deleterious to the receiving streams. Since the opening of the first commercial coal mine over 150 years ago, the harmful effects of mine drainage discharges have become increasingly more significant. What was once a localized problem in the early days of the mining industry is now widespread. Today, after the production of over 1 billion tons of bituminous coal and 5 billion tons of anthracite coal, more than 1,000 miles of streams in the Study Area are rendered acid by mine drainage discharges. Mine drainage has rendered at least an additional 1,000 stream miles undesirable for some water uses.

Increasingly stringent regulatory control has been placed on the mining industry by State water pollution control agencies and pollution caused by active mines is expected to diminish. Most of the mine drainage entering the streams of the Study Area originates, however, in abandoned mines. Responsibility for abatement of pollution from this source has fallen to State, local, and Federal agencies. A rational, efficient approach to the problem on a basin-wide basis involves the identification of pollution sources, their effect on stream quality, and the development of a comprehensive pollution abatement plan based upon costs and benefits to be derived. This report is intended as a first step toward development of such a plan.

IV. FORMATION OF MINE DRAINAGE

A. Chemistry

Many minerals are sufficiently reactive to form water soluble salts when they are mined and exposed to air. Ground or surface water coming in contact with the minerals dissolves the salts and carries them to the surface, causing stream pollution. In the course of the mining of coal, large amounts of sulfuritic material are exposed to the atmosphere. When water comes into contact with these materials, sulfides and other minerals are dissolved, producing a drainage that contains ferrous and ferric iron, aluminum, calcium, and magnesium sulfates. In addition, manganese, sodium, potassium, and other elements may be present in the resulting drainage as chlorides, carbonates, and sulfates.

The concentration of the pollutants present in mine drainage is a function of the availability of metallic sulfides, water, and oxygen, their exposed surface area, their contact time with each other, along with temperature and various catalytic agents. Sulfuritic materials associated with the various mineral deposits are the principal precursors of the salts and sulfuric acid found in coal mine drainage. The minerals, mainly pyrite, oxidize in the presence of air and water to form ferrous sulfate and sulfuric acid. Although investigators differ concerning the actual reactions and mechanisms involved in the formation of acid drainage, the overall reactions can be represented by the following equations:

$$\underset{\text{(pyrite)}}{2\ FeS_2} + \underset{\text{(oxygen)}}{7\ O_2} + 2\ H_2O \longrightarrow \underset{\text{(ferrous sulfate)}}{2\ Fe\ SO_4} + \underset{\text{(sulfuric acid)}}{2H_2\ SO_4}$$

$$Fe\ S_2 + 3\ O_2 \longrightarrow Fe\ SO_4 + \underset{\text{(sulfur dioxide)}}{SO_2}$$

$$2\ SO_2 + O_2 + 2\ H_2O \longrightarrow 2\ H_2\ SO_4$$

The reaction yields two moles of hydrogen ions (acidity) for each mole of iron oxidized.

Initially, the iron in mine drainage is in the ferrous state; however, after contact with air, ferrous iron oxidizes to ferric iron, i.e.

$$\underset{\text{(ferrous sulfate)}}{4\ Fe\ SO_4} + 2H_2\ SO_4 + O_2 \rightleftharpoons \underset{\text{(ferric sulfate)}}{2\ Fe_2\ (SO_4)_3} + 2H_2O$$

Dependent upon pH, temperature, and concentration of constituents, the reaction proceeds:

$$Fe_2\ (SO_4)_3 + 6\ H_2O \rightleftharpoons \underset{\text{(ferric hydroxide)}}{2\ Fe\ (OH)_3} + 3\ H_2\ SO_4$$

and/or

$$Fe_2\ (SO_4)_3 + 2\ H_2O \rightleftharpoons \underset{\text{(basic ferric sulfate)}}{2\ Fe\ (OH)\ (SO_4)} + SO_4$$

In the absence of acid, basic ferric sulfate may precipitate directly according to the reaction:

$$4\ Fe\ SO_4 + O_2 + 2\ H_2O \rightleftharpoons 4\ Fe\ (OH)\ (SO_4)$$

There is some question as to whether the basic ferric sulfate is a discrete compound or a ferric hydroxide containing occluded sulfate.

In the presence of strong acid concentrations, ferrous sulfate may hydrolyze as follows:

$$Fe\ SO_4 + 2\ H_2O \rightleftarrows Fe\ (OH)_2 + H_2SO_4$$

B. Microbiology

Although there are conflicting opinions among researchers as to the importance of micro-organisms in the productions of mine drainage pollution, there is evidence to indicate that micro-organisms do contribute to initial pyrite oxidation. A number of bacterial species (*Thiobacillus thiooxidams*, *Thiobacillus ferroxidams*, and *Ferrobacillus ferroxidams*) have been isolated from mine drainage waters, but the extent of their role in the formation of mine drainage pollution is not presently known.

V. SOURCES OF MINE DRAINAGE

The gradual increase in the detrimental effect of mine drainage pollution in the Study Area is closely associated with the commercial mining of coal. Mining operations are carried out in a variety of ways depending primarily upon the location and configuration of the coal deposit to be mined. The way in which the mine is developed and operated has a profound effect on the quality and quantity of mine drainage produced by the mine.

Mines are classified as either "deep mines" or "surface mines".

A. Deep Mines

Deep mines may be further classified as "shaft", "slope", or "drift" mines.

1. Shaft

A shaft mine is one in which a vertical opening is driven downward to a coal seam which may not outcrop at the ground surface at that point. Coal seams which are mined through shaft openings usually lie beneath the ground water table. During the period the mine is active, water which finds its way into the mine must be pumped to the surface through the shaft or through boreholes drilled for this purpose.

2. Slope

A slope mine is one in which the coal is removed through an entry which slopes downward to intercept the coal seam. As is the case with shaft mines, while mining is being carried out, water which enters the mine must be pumped to the surface. When shaft and slope mines are abandoned, infiltrating ground water fills the mines to the natural level of the ground water table in the area or to a level in the mine at which the water can find its way to the surface by gravity. This "natural" inundation of sulfuritic material has been observed to have a beneficial effect on the quality of drainage from mines. In the Anthracite Area many shaft and slope mines are kept dewatered by a system of rock tunnels which were driven expressly to provide gravity drainage of the mines in a given coal basin.

3. Drift

A drift mine is one in which the opening is driven into the outcropping of the coal seam. Drainage from a drift mine is usually by gravity through open channels, however, local dip areas may be dewatered by siphoning or pumping while the mine is active. Drift mines are identified as a major source of mine drainage in the Study Area because, when abandoned, they tend to discharge mine drainage with a quality equal to or worse than that experienced while the mine was active.

B. Surface Mines

Drainage from surface mines may be either by gravity or pumping, depending upon the elevation of surface drainage in the area. In addition to provisions for handling ground water which enters surface mines, steps must be taken to divert surface drainage in such a way that it does not enter the mine workings.

Surface mines may be sub-divided into strip and auger mines.

1. Strip

A strip mine is one in which the coal is removed from an open pit following complete removal of strata overlying the coal seams.

2. Auger

Auger mining is usually associated with some form of strip mining. However, it is also used to extract coal near the outcrop which was not recovered by earlier deep mining or where underground mining is not feasible. Coal is extracted by boring horizontally into the exposed coal seam.

Most of the coal production in the Study Area has been accomplished by deep mining methods; however, in recent years (since 1945), the percentage of coal produced by stripping operations has steadily increased. At present approximately 60 per cent of the coal production in the Study Area is by the strip mine method.

Studies conducted by the Chesapeake Bay-Susquehanna River Basins Project have located a considerably smaller number of major mine drainage discharge sources than the total number of mining operations recorded to have been located within the Study Area. Some of the reasons for this difference are:

1. Studies were conducted during summer low stream flow periods when mine drainage flow would be expected to be at a minimum. Mines which discharge only during wet weather periods were thus not located.
2. Interconnection of mine workings, both intentionally and unintentionally, has in many cases consolidated drainage from many mines into one discharge.

3. Many abandoned mines have been sealed in the course of mine sealing programs and as a result of surface mining operations.
4. Some mines have filled with water, interrupting the air-water-sulfuritic material interaction. Discharges from these mines do not exhibit the characteristics of mine drainage and were, therefore, not considered in the tabulation of "mine drainage" discharges.

The number and acid loading of mine drainage sources located to date are summarized by source category as shown in the table on page V. - 6.

The quality and quantity of mine drainage produced from a mining operation is dependent upon a number of factors. The chief factors are:

1. The operating status of the mine (i.e. active or abandoned).
2. Hydrologic and geologic features of the surrounding terrain.
3. The type of mining method employed.
4. Availability of precursors (air, water, and sulfuritic materials).
5. Contact time of the required precursors.
6. Character of surface topography.

MAJOR MINE DRAINAGE SOURCES
CHESAPEAKE BAY-SUSQUEHANNA RIVER AND DELAWARE RIVER BASINS

Basin	Active Operations				Inactive Operations				Inactive Deep and Strip		Total	
	Deep Mines		Strip Mines		Deep Mines		Strip Mines					
	No.of Disch.	Acid Load Lb/day	No.of Disch.	Acid Load lb/day	No.of Disch.	Acid Load Lb/day	No.of Disch.	Acid Load Lb/day	No.of Disch.	Acid Load Lb/day	No.of Disch.	Acid Load Lb/day
W. Br. Susquehanna River	4	4,200	12	19,000	238	176,000	167	78,800	34	4,700	455	282,700
Juniata	-	-	-	-	30	37,500	-	-	-	-	30	37,500
Tioga	-	-	-	-	13	15,400	3	900	-	-	16	16,300
Lackawanna & Main Stem Susquehanna River	34	509,300	-	-	81	225,700	9	23,900	-	-	124	758,900
North Br. Potomac River*												
Delaware River-Lehigh River & Schuylkill River	8	400	2	200	38	55,000	6	1,600	-	-	54	57,200
											679	1,152,600

*Data not presently available

The production of mine drainage from a mining operation may be continuous or intermittent. Underground mines developed below the ground water table usually "make" mine drainage on a continuous basis; the concentration of the pollutant varying as a function of the volume of water entering the mine, contact time, and available precursory materials. In cases where the ground water table is below the mining level during some seasons or when the mine receives direct surface water contributions, the discharge quality and quantity may vary greatly.

In surface mines the production of the pollutant is often intermittent, generally occurring during and immediately after periods of precipitation. Runoff in stripped areas may find its way to a surface stream or be trapped in inadequately restored trenches or pits formed during the stripping operation. When the runoff is trapped, pools which may contain high concentrations of mine drainage indicators are formed. During subsequent periods of high runoff, these pools may overflow, releasing concentrated "slugs" of mine drainage pollution to receiving streams. The pools thus formed constitute reservoirs of potential mine drainage. They often drain slowly into the backfill to emerge in the form of mine drainage seepages downslope from the stripping operation. They may also drain to underground mines underlying the stripped area, thus increasing the mine drainage flow from these mines.

Mine drainage may continue to flow from both surface and sub-surface mining operations long after the mines have been "worked-out" and abandoned. As long as the precursor materials (air, water, and sulfuritic material) are available, the mine will continue to produce the pollutant.

Pollution having mine drainage characteristics may also originate at refuse and "gob" piles associated with mining operations. The refuse piles are spoil areas where impurities removed from the mined coal are deposited. The impurities in the spoil area may contain a sulfur-bearing material; and, when exposed to air and water, mine drainage type discharges may result. The pollution emanating from these "gob" piles is usually intermittent, occurring only during and immediately after periods of precipitation. Several instances have been found, however, where the piles interrupt surface drainage. The water passing through the spoil banks thus constitutes a vehicle for transport of soluble salts, thereby forming a "mine drainage discharge". Although discharges from spoil piles may be extremely significant, particularly in small watersheds, information is not presently available to permit a general statement on the effect of spoil piles on water quality on a basin-wide basis or to estimate the cost of reclamation of spoil piles which cause pollution. This facet of the mine drainage problem will be discussed more comprehensively in future reports.

Both surface and deep mining operations are responsible for the heavy silt load carried by many of the streams in the area. During surface mining operations, large tracts of land are completely denuded, exposing the soil to erosion by water and wind. Coal fines are often introduced to receiving streams by coal processing operations and by surface runoff from piles of coal refuse. This material may itself contain sulfuritic material and constitute a source of "mine drainage" pollution.

VI. DAMAGES

When mine drainage is discharged to a receiving stream, limitations may be placed on the value of the stream and adjoining land for recreational, industrial, municipal and other uses. The effect of mine drainage on stream quality is not necessarily limited to a reach near the point of origin. Although the diluting and neutralizing effect of unpolluted streams generally limits acid conditions to streams within the coal fields, damages attributable to other mine drainage indicators are often experienced far downstream from the point of origin. Although the damages attributable to mine drainage in the Study Area are not difficult to enumerate, they are difficult to completely evaluate in monetary terms. The only information available on the monetary value of damages attributable to mine drainage relates to sports fishing. Although this damage is certainly not the only one, it is believed to be the largest in monetary terms and by far the most significant in the Study Area at present. Future development of the Basin's water resources may, however, create increased demand for the use of streams receiving mine drainage, thereby increasing calculable damages. It is hoped that more detailed information on monetary damages can be developed for inclusion in future Project Mine Drainage Reports. Although damages caused by mine drainage may be categorized in many ways, for this report we have chosen to categorize these effects in terms of "in-stream", "withdrawal", and "other" effects.

A. In-Stream Damages

The most striking and probably most economically important in-stream damage caused by mine drainage is its effect on aquatic life. Only a limited number of aquatic forms can exist in an environment strongly influenced by mine drainage. Mine drainage produces low pH values and the formation of toxic precipitates, which restrict, and in some cases practically eliminate, all aquatic life. It is generally agreed that an aquatic environment having a pH outside the range 6.3 to 9.0 cannot support a balanced aquatic population. If the pH drops below 6, as it often does in streams influenced by mine drainage, both macroscopic and microscopic populations are adversely affected.

The most economically important members of the macroscopic population are game fish and the organisms that make up their food supply. A draft report prepared by the U. S. Fish and Wildlife Service(1) states: "There are about 3,000 acres involved in the 824 miles of cold water streams and 3,300 acres in the 206 miles of warm water streams affected by mine acids. Elimination of this adverse factor in all streams so affected would result in increased fishing in the amount of 500,000 fishing days annually with a recreational value of $1,125,000 and related expenditures valued at $2,660,000 annually".

Unsightly precipitates, accumulations of inert "silt", and low pH combine to render most of the stream miles discussed above unsuitable for other recreational uses.

Mine drainage depresses the microscopic population in a stream. This may retard the ability of a stream to biochemically stabilize sewage or organic industrial waste. The organic material is, in a sense, "pickled" in the acid water and is stabilized further downstream at a point where stream alkalinity increases.

A more subtle effect of mine drainage on industrial and municipal waste disposal is its fostering of a general disregard for streams presently polluted by mine drainage. The present limited uses of these streams depress the incentive for sewage and industrial waste pollution abatement on the part of Basin residents. Their attitude seems to be that until mine drainage pollution is abated and a full spectrum of uses restored, sewage and industrial discharges are not really polluting the stream. This philosophy is reflected in the attitude of many area residents who use the streams as a dumping ground for garbage and trash.

The constituents of mine drainage tend to erode concrete structures and corrode metal structures in the stream. This effect may also be observed on intake structure and the raw water piping of "withdrawal" users of mine drainage effected streams.

B. Withdrawal Uses

Mine drainage has a definite adverse effect on the use of streams for industrial, municipal, and agricultural water supply. The principal sources of the adverse effect are sulfuric acid, iron, manganese, aluminum, calcium, and magnesium salts contributed by mine drainage.

In water treatment plants, high acidity and low pH may result in adverse effects in chemical coagulation, softening, and corrosion control. Corrosion control is the major problem of most industrial users; however, industrial establishments employing chemical or biological processes experience serious difficulties if the iron concentration or acidity of the water supply is not or cannot be adequately controlled by their water treatment plants.

Both iron and manganese create serious problems in public and in some industrial water supplies. The problems associated with iron are caused by the precipitation of iron salts, which are objectionable from an aesthetic point of view. Iron salts stain plumbing fixtures and laundry and interfere with certain industrial processes. Iron also supports the growth of filamentous iron bacteria which restrict and may completely stop the flow of water in distribution lines. Manganese has much the same effect as iron, except that the precipitate formed is black.

The U. S. Public Health Service has set the maximum suggested concentration of iron and manganese in public water supplies at 0.3 milligrams per liter (mg/l) and 0.05 mg/l, respectively. Some industrial processes are, however, adversely affected by any measurable concentration.

Some sulfate compounds and the end-products of their reaction with calcium and magnesium carbonate (the principal constituents of the alkalinity of many streams) produce permanent hardness in water. Hardness is objectionable in public supplies, particularly because consumers are forced to use more soap for cleaning purposes. Permanent hardness in boiler feed water forms scale, which cuts down the heat exchange efficiency of boilers and is thus objectionable to industrial water users.

The undesirable characteristics of mine water can be removed by modern, adequately designed water treatment plants. To an industrial establishment contemplating locating at a particular site, the additional cost of treating water polluted by mine drainage could, however, be a very important consideration.

The use of mine drainage for crop irrigation tends to increase the acidity of the normally acid soils of the Study Area and may cause a chemical reaction in the soil, adversely affecting its physical properties.

In general, withdrawal uses of streams influenced by mine drainage are very limited in the Study Area. In most cases water users have been able to utilize ground water or streams unaffected by mine drainage to meet their needs to date. No information is presently available on the incremental cost of utilizing these sources as compared to the cost of utilizing mine drainage affected streams if they were unaffected.

C. Other Damages

In addition to damages directly assignable to water uses, other damages, real but presently undefined in monetary forms, may occur in areas drained by mine drainage polluted streams. Unsightly deposits of iron salts have ruined the natural beauty of many streams discouraging recreational use of the streams and adjoining land. This impairment of use may be reflected in depression of adjacent property values. Industrial or commercial development nearby may be discouraged because of aesthetic considerations associated with the mine drainage polluted streams.

VII. ABATEMENT AND CONTROL MEASURES

Over the many years that mine drainage pollution has been recognized as a problem, numerous methods have been advanced as possible solutions. The methods may be categorized as either "abatement" or "control" measures.

"Abatement measures" as discussed here are considered to be methods intended to reduce amounts of mine drainage pollutants at their source. "Control measures" are considered here to be measures intended to eliminate or reduce the polluting effects of mine drainage after the pollutants have been formed and are present in the mine discharge or surface stream. It is not the purpose of this report to exhaustively discuss the applications of various specific methods. Several of the basic abatement and control methods are briefly discussed below. The least expensive solution of a given problem could involve any or the combination of any of the following:

A. Abatement Measures

Abatement measures found to have some degree of success are based upon the prevention of the simultaneous contact of air, water, and sulfuritic material. Some of these measures are:

1. Mine Sealing

Traditionally the term "mine sealing" has been used to describe efforts to exclude air from deep mines by sealing known openings while permitting the flow of water from the mine. This method is generally considered to be ineffective because the mine continues to "breathe" through hidden fissures after all visible entries have been sealed.

A variation in this procedure, segregation and burial of acid-forming refuse, is used successfully to prevent and abate mine drainage discharges from surface mines and coal refuse piles. An impervious clay blanket is used to cover the material and prevent oxidation of the sulfuritic material.

2. Inundation

This method utilizes the observation that sulfuritic material immersed in water cannot come into contact with the third basic requirement for mine drainage formation, air. The method is applicable to both deep mines and surface mines. Flooding of certain shaft and slope mines and strip mines, in which the sulfuritic material lies below the level of the pool formed, has been observed to prevent formation of mine drainage.

3. Water Control and Diversion

This measure is probably the most universally applicable of the measures described here. Although soluble metallic salts, the pollutant in mine drainage, may be formed by the action of air, air moisture, and sulfuritic material, flowing water is needed to dissolve and carry the salts from the mine to form mine drainage. Complete exclusion of water from a mine or elimination of contact of water with sulfuritic material while in the mine would eliminate mine drainage pollution. In active and inactive mines, both strip and deep, reduction in the amount of mine drainage pollutants discharged can be accomplished by reducing water flow into the mine.

While the mines are still active, water that does enter may be conveyed back to a surface water course quickly and with little contact with sulfuritic material by the utilization of a system of pumps and closed conduits. In abandoned mines, where this control is not possible, emphasis must be placed upon preserving surface drainage patterns and minimizing the contribution of surface water to the mines.

Regrading and planting of areas disturbed by surface mines or deep mine subsidence promotes surface runoff, minimizes perculation of water impounded in the disturbed area through sulfuritic material disturbed by the surface mining, and minimizes contribution of water to underground mines which may underlie the area.

A major secondary benefit results from the reclamation of areas disturbed by mining. The land is restored to a configuration which makes it more suitable for beneficial use.

B. Control Measures

It is not always feasible to abate mine drainage pollution by interrupting the chemical processes by which the pollutant is formed. In such cases a variety of control measures may be utilized to eliminate or reduce its effect on stream quality. Some of these are:

1. Treatment

Numerous methods have been proposed for the treatment of mine drainage to remove its polluting properties. Probably the most widely practiced treatment method to date has involved the addition of lime, limestone, soda ash, caustic soda, or other basic material to neutralize acid and induce precipitation of certain metallic salts. Considerable research and development work has been accomplished on variations of this method by both public agencies and private industry. A number of treatment plants of this type are in routine operation at present. A major disadvantage of this method is the operation cost, which has been reported to range as high as $1.30/1,000 gallons. Major expenditures involved in this method include the cost of the basic material added and the cost of sludge removal. The precipitate formed in the course of treatment is frequently difficult to dewater to the point at which landfill disposal can be utilized. A second disadvantage of this method is its failure to remove certain dissolved mineral constituents and only a portion of the suspended material. Added in the process are materials which may in themselves cause pollution. The hardness of the treated water, for example, may be raised by lime neutralization treatment.

Other treatment methods proposed involve removal and concentration of pollutants in mine drainage. Many of the methods proposed are also being investigated in conjunction with the Federal desalinization program. Some of the methods are ion exchange, evaporation, and electrodialysis. Major problems associated with these methods involve high operating cost and disposal of the separated pollutants. No full-scale treatment plants utilizing these principles have as yet been constructed in the Study Area. The Pennsylvania Coal Research Board has, however, sponsored the design of experimental treatment plants which utilize evaporation and ion exchange principles.

At present a need exists for reliable information on the cost of constructing and operating various types of treatment facilities under a variety of conditions. Cost data presently available have been derived mainly from bench-scale and pilot-plant studies and may not be applicable to all field conditions encountered. Research and development programs presently in progress and operating data from full-scale plants in operation and soon to be placed in operation should provide more reliable data on which to evaluate treatment alternatives in the future.

2. Impoundment and Controlled Release of Mine Drainage

In certain situations, benefits may be realized from impounding mine drainage for release in such a way as to minimize its effect on stream quality. The objective of this procedure is to maximize utilization of the assimilative capacity of the receiving stream.

For several years, the storage capacity of underground mine water pools in the Northern Anthracite Field has been utilized to store mine water during periods of low flow in the Susquehanna River. The stored water is discharged to the river during periods when streamflow and assimilative capacity are high.

The same general procedure could be followed utilizing surface impoundments. An advantage of utilization of surface impoundments over subsurface impoundments is the reduced likelihood that additional mine drainage will be formed. Variation of underground pool levels may result in further deterioration of the quality of the impounded water because of increased contact with sulfuritic material. Preliminary results of studies of surface impoundments conducted by a private contractor indicate that impoundment has no significant effect on the mineral content of mine drainage. These studies and a parallel study being conducted in cooperation with the Corps of Engineers are expected to be completed in late 1967.

3. Streamflow Regulation

This method is closely related to impoundment and controlled release of mine drainage. The objective is to impound good quality water for release during periods of minimum stream assimilative capacity to increase the assimilative capacity of streams receiving mine drainage. The impounded water should be high in alkalinity and low in mine drainage indicators so that the releases may have the dual value of neutralizing acid while decreasing concentrations of other mine drainage indicators by dilution.

Obviously streamflow regulation is applicable only to situations in which the stream's natural assimilative capacity is adequate to prevent pollution under most conditions. The releases act simply as loans of good quality water which are drawn from the stream's total assets. A stream perennially polluted by mine drainage cannot be reclaimed by flow regulation alone.

Because of variations in buffer systems in waters encountered in areas in which this method is applicable, it is presently impossible to accurately predict the quality resulting from blends of mine drainage and natural waters. This gap in our technical knowledge makes it presently impossible to accurately estimate the amount of streamflow regulation required for mine drainage pollution control purposes. Studies are in progress, both by Federal Water Pollution Control Administration personnel and a private contractor, to develop procedures for predicting the resultant quality of blends of mine drainage and natural water.

4. Conveyance and Diversion

Under certain conditions the effects of mine drainage on water uses may be controlled by conveying the mine drainage to another stream which has a greater assimilative capacity or a less critical water use. Diversion of good quality water between watersheds may also be feasible in some cases to increase the assimilative capacity of the receiving stream. In contrast to the procedure described under "Streamflow Regulation", inter-watershed diversion could result in a perennial benefit to the quality of the receiving stream.

In order to rationally implement this method, procedures must be developed to permit prediction of the quality resulting from the blending of mine drainage and natural water.

VIII. STATE ACTIVITIES AND REGULATIONS

A. Pennsylvania

Pennsylvania's mine drainage pollution control program began in 1945 with the amendment of the State "Clean Stream Law" giving the State Sanitary Water Board limited authority over acid mine drainage. Coal mine operators were required to obtain Board approval of a plan of drainage before a mine could be opened, reopened, or continued in operation. The Act prohibited the discharge of acid mine drainage into "clean waters", which were defined as those waters which were, at the effective date of the Act, unpolluted and free from industrial waste and authorized sewage discharges except for discharges which received secondary treatment. The Act also authorized the Board to provide necessary diversion works to carry acid mine drainage away from clean waters for discharge to polluted or "unclean waters".

The provisions of the 1945 amendment to the "Clean Stream Law" had the effect of preventing pollution of streams which were unpolluted on the effective date of the Act. They did not, however, provide for effective control of discharges to streams which did not fall within the rather narrow definition of streams to be protected.

In 1965 the "Clean Stream Law" was again amended, removing all exemptions in the Law relating to mine drainage.

Under the provisions of the 1965 amendment which became effective on January 1, 1966, mine drainage is subject to the same controls as sewage and industrial waste. Discharges may not cause pollution. The intent of the amended law is to "restore to a clean, unpolluted condition all waters of the Commonwealth." Regulations adopted by the Board to implement the most recent amendment to the Law include the provision that discharges from active mines have net alkalinity and a maximum of 7 mg/l dissolved iron.

In addition to making water pollution control laws more stringent, the Pennsylvania Legislature has over the years progressively increased requirements concerning the backfilling and restoration of areas disturbed by mining. Present requirements, which are administered by the Department of Mines and Mineral Industries, demand prompt and, in some cases, complete restoration of the disturbed area. Regulations have been adopted to prevent acid drainage and soil erosion from areas disturbed by strip mining, both during and after mining is completed.

Present State mine drainage pollution control and strip mine reclamation regulatory authority appears to be adequate to essentially prevent additional stream quality degradation as a result of future mining activities. The extent of stream quality degradation from future mining will depend largely upon the degree of enforcement of the present authority and upon technical factors which could make complete enforcement of the authority of the Sanitary Water Board impractical or impossible in some cases.

In addition to the enforcement activities described above, considerable effort is being expended by both the Sanitary Water Board and the Coal Research Board, an administrative agency within the Department of Mines and Mineral Industries, to determine and demonstrate new methods of abating mine drainage pollution. These activities are intended to demonstrate ways of preventing pollution from active operations as well as determining methods of abating pollution from the thousands of abandoned mines already causing pollution.

Sanitary Water Board and Department of Health activities include:

1. Sponsorship of basic research into the formation of polluting constituents in mine drainage. This work was carried out from 1946 through 1953 at the Mellon Institute in Pittsburgh and resulted in the discovery of basic methods of minimizing and preventing formation of polluting characteristics in mine drainage.
2. Sponsorship of several engineering studies intended to determine the solutions and associated costs of

mine drainage pollution abatement in the Susquehanna River between the confluence with the Lackawanna River and the confluence with the West Branch Susquehanna River.

3. Sponsorship of an engineering study of the feasibility of neutralizing streams in a portion of the Slippery Rock Creek Basin in the Ohio River Basin.

The Coal Research Board and Department of Mines and Mineral Industries have been very active in pollution abatement activities. Their activities include:

1. Sponsorship of an investigation into the feasibility of adapting distillation processes currently used for desalinization of sea water to the treatment of mine drainage.
2. Sponsorship of pilot plant studies of lime neutralization process as a mine drainage pollution abatement method.
3. Sponsorship of the design of an ion exchange plant to remove objectionable constituents in mine drainage.
4. Sponsorship of the design of a lime neutralization facility to treat a major mine drainage discharge in the Sinnemahoning Creek watershed.

In early 1967 the Pennsylvania Legislature adopted a $500 million conservation bond issue which was approved by the voters by a wide majority. The bond issue will make approximately $200 million available to the Department of Mines and Mineral Industries for the reclamation of areas disturbed by mining and for the abatement of mine drainage pollution. The funds will be expended over a 10-year period.

B. Maryland

In March 1967 the Maryland Legislature passed a new strip mining law which differs from the old (1963) law in several respects. The 1967 law contains a provision for pollution control: "The operator is responsible for the prevention of avoidable stream pollution in excess of standards established by the Department of Water Resources." The law specifically states that the Bureau of Mines shall not issue additional permits to an operator who has failed to meet the provision for pollution control.

The 1967 law requires backfilling to "as near normal as is satisfactory to the Bureau" (of Mines) and replanting of the disturbed area. The 1963 law required backfilling to a specific geometrical configuration but did not require replanting.

The 1967 Maryland law is now in the hands of the Land Reclamation Advisory Committee. After review by the Committee, administrative regulations will be issued by the responsible State agencies.

Maryland has no laws or regulations governing deep mine discharges. The only permit required is a certification by the operator that he will comply with the Bureau of Mines' safety regulations.

C. West Virginia

Legislation recently enacted in West Virginia provides, for the first time, statutory control of drainage from strip mining operations. Under the new law, strip mining, except for safety regulations, is placed under the control of the Director of the Department of Natural Resources. The law requires public liability insurance for operators, maintenance of a reclamation fund, and submission of a plan of operation before mining. The Director of the Department of Natural Resources has the power to cancel or prohibit strip mining to prevent destruction of natural beauty in areas as extensive as an entire watershed. He also has broad powers to impose rules and regulations. Until this law was passed, West Virginia's only basis for control of mine drainage was her membership in the Ohio River Valley Water Sanitation Compact and her agreement to carry out provisions of ORSANCO resolutions governing mine drainage. Administrative rules and regulations issued earlier under ORSANCO membership now have a statutory basis. These regulations are probably adequate to control mine drainage pollution from strip mines. The new law provides no control of pollution caused by deep mines.

IX.. STUDY PROCEDURES

Field investigations, sampling programs and laboratory analyses were conducted by personnel of the Chesapeake Bay-Susquehanna River Basins Project primarily during the periods of June through October in 1964, 1965, and 1966.

A. Field Investigation and Sampling Procedure

The field investigations were conducted in two phases - "Reconnaissance" and "Control Sampling".

During the reconnaissance phase of the survey, primary effort was directed toward the identification of Study Area watersheds which contributed significant amounts of mine drainage pollution. Existing Federal, State, and industrial data were reviewed. To the extent possible, streams affected by mine drainage pollution and sources of the pollution were identified and located on U. S. Geological Survey or county maps. In cases in which the existing data were inadequate to characterize mine drainage pollution, survey crews made field determinations of pH, alkalinity, acidity, conductivity, flow, and, as practicable, ferrous iron. Field survey crews also located and identified point sources of mine drainage pollution when possible. Information supplied by the States of Maryland and West Virginia was used to locate sampling stations in the Potomac Basin.

Results of stream biological surveys conducted during the course of the Chesapeake Bay-Susquehanna River Basins Project

Study were used as an aid in determining the streams affected by mine drainage pollution.

Based on existing data and the results of the reconnaissance survey, control sampling stations were established on all streams significantly affected by mine drainage pollution. Depending upon the prevailing conditions, six to eight samples were normally taken at each station. Samples taken were iced and transported to the laboratory for physical and chemical analyses. Time in transit from the field to the laboratory usually varied from 6 to 24 hours. In the Potomac Basin, most of the analyses were made in the field. At the time of the sampling, field determinations were made of the flow, pH, and specific conductivity. During this phase of the Study, every effort was made to locate and characterize every significant discharge. Detailed investigations in the Sinnemahoning, Kettle Creek, Chest Creek, Pine Creek, and other minor watersheds in the West Branch Susquehanna River Basin, as well as in minor watersheds in the Anthracite and Semi-Anthracite Areas, are yet to be completed. In the Potomac Basin, the Western Maryland Mine Drainage Survey by the Maryland Department of Natural Resources lists significant discharges in Maryland. Investigation of sources in West Virginia remains to be completed.

Considerable information on major mine drainage discharges and their effects on stream quality is still needed. Basic data collection is planned for the summer of 1967.

Responsibility for reporting on mine drainage in the Delaware Basin was assigned to the Chesapeake Bay-Susquehanna River Basins Project late in the summer of 1966. The time and personnel available permitted only a reconnaissance and limited laboratory analyses of discharges found flowing during the period of search and study. The limited period did not allow the development of a population of data similar to that developed in the area of prime responsibility, the Chesapeake Bay-Susquehanna River Basins.

B. Laboratory Procedures

Mine drainage pollution is generally characterized by increased concentrations of:

1. Specific indicators above usually accepted levels; or
2. The presence of ions of elements considered unique to mine drainage discharges.

Although these indicators may be common to some types of industrial waste or result from natural discharges, their sources can be determined as well as their significance.

In the course of the Project's Mine Drainage Study efforts, samples of both discharges and receiving streams were analyzed for the following indicators:

1. Physical
    a. pH

  - b. Conductivity
  - c. Solids
  - d. Temperature
- 2. Chemical
  - a. Acidity
  - b. Alkalinity
  - c. Iron - Ferrous and Total
  - d. Hardness
  - e. Calcium
  - f. Magnesium
  - g. Manganese
  - h. Aluminum
  - i. Sulfate

Methods used and significance of the individual analyses are discussed below:

1. pH - by Potentiometric measurement (pH meter) (Laboratory and Field). pH is a term used to express the degree of acidity or alkalinity of a system and is defined as the logarithm of the reciprocal of the hydrogen-ion concentration. The pH scale is a logarithmic scale. Fractions of a pH scale do not represent arithmetic values but rather logarithmic values.

The pH measurement is a measure of the actual hydrogen ion concentration (or activity) present in a given system at a given time and temperature and is, therefore, the only true measure of how such a solution will affect another system which is sensitive to hydrogen of hydroxyl ions.

Natural waters usually exhibit a pH in the range of pH 6.0 to 9.0. Generally, acid mine drainage will vary from pH 2.5 to 6.0. Alkaline mine drainage occurs with pH in the order of 6.0 to 8.0. The pH of the receiving stream varies according to the severity of pollution and the state of reaction of the pollutants.

2. Conductivity - by Conductivity Bridge (Laboratory and Field)

Conductivity is expressed in terms of the reciprocal of resistance (mho) and is a measure of the electrical conducting power of the systems. The measurement indicates the degree of dissociation of the constituents of the system. It is generally indicative of the concentration of dissociable constituents, essentially inorganic, and is thereby associated with the amount of dissolved matter (dissolved solids) in solution. The measurement is dependent primarily upon the number of molecules concerned (not their nature) and is influenced by temperature. Waters uncontaminated by mine drainage exhibit conductivities in the order of 100 micro mho. Measurement of mine drainage discharges varies generally from 500 to 8,000 micro mho. Receiving streams exhibit intermediate measurements depending upon the degree of dilution.

3. Solids

a. Non-filterable (suspended) solids - by filtration of a standard volume (250 ml) drying to constant weight at 105°C (Standard Methods-12th Edition).

This measurement determines that fraction of particulate matter retained by the filter, i.e., so called suspended matter of a given sample procured under the existing sampling conditions.

b. Filterable (dissolved) solids - by evaporation of filtrate from the previous paragraph and drying the residue to constant weight at 105°C. Measurement of filterable solids indicates the concentration of materials dissolved and in solution.

c. Total Solids - by calculation, i.e., the sum of the two preceding paragraphs.

4. Acidity

a. Cold Acidity - by potentiometric titration to pH 8.3 (SFS modification of Standard Methods-12th Edition). Laboratory analyses were conducted potentiometrically. Field analyses were conducted potentiometrically or colorimetrically. This procedure measures the titratable acidity including volatile acidity which can be made to combine with a base. It is a measure of the uncombined hydrogen ion immediately present and that which can be available from all potential sources under the titration conditions.

In samples containing high concentrations of potential acidity precursors, the total potential acidity may not be made available under the conditions of the determination.

Mine drainage normally contains acidic precursors such as ferrous iron, manganese, and aluminum. Where concentrations are low, (less than 10 mg/l), the reactions leading to the total release of hydrogen ion will usually occur under the titration conditions. However, where the concentrations are high, (greater than 10 mg/l), reactions during titration may be incomplete under the conditions of a cold titration. Preoxidation, either by addition of ozone, peroxide, or heating, is therefore required for the measurement of total acidity.

b. Hot Acidity - by potentiometric titration to pH 8.3 end point. (SFS modification of Standard Methods-12th Edition)

This procedure measures the titratable acidity (hydrogen ion) which is available in the sample and which is made available by heating the sample to boiling temperature for 2 minutes with the addition of hydrogen peroxide. The sample is either cooled to room temperature under controlled conditions (CO_2 free atmosphere) or titrated at 70 - 90°C. Volatile acidity produced during the heating step may be removed and thereby not titrated..

The method determines the acidity made available from potential sources, one of which is ferrous iron. It does not measure any contribution to acidity of volatile constituents either present initially or produced by subsequent reactions. In effect, the "hot acid" titration may determine a portion of the potential acidity present when volatile acidic precursors are present. This determination is applicable to relative measurements such as the effect of an abatement procedure or the characterization of a discharge. However, it may not be useful in stream analysis since it does not measure all sources of acidity.

5. Alkalinity - by potentiometric measurement. Titration to pH 4.5 (Standard Methods-12th Edition). Laboratory analyses were conducted potentiometrically. Field analyses were conducted potentiometrically or colorimetrically.

This procedure measures the titratable alkalinity of the system which in most waters of this Basin is essentially bicarbonate and/or carbonate in origin.

Under the conditions of the determination, alkaline mine drainage exhibits a final positive alkalinity when the acidity produced in the course of the titration does not exceed the available alkalinity. It is, therefore, essential that reactions yielding acidity be completed before the alkalinity determination is attempted.

6. Net or Residual Alkalinity - by calculation

This calculation is the difference between the alkalinity and acidity determined by cold titration on a given sample.

For purposes of calculation, acidity is considered to be equivelent to negative (-) alkalinity.

7. Sulfate - by precipitation with benzidine-dihydrohloride

This procedure measures the concentration of sulfate of the sample and is considered an indicator of mine drainage pollution. Unpolluted waters of the Basin contain low levels of the indicator derived from the leaching of soils, rock, etc.

Mine drainage originates as the result of the oxidation of pyrite associated with coal-bearing strata. The sulfur is ultimately oxidized to sulfate. Therefore, levels of this indicator above natural stream concentration are indicative of mine drainage pollution. Whereas relatively unpolluted waters contain concentrations normally below 50 mg/l, mine drainage discharges often exhibit concentrations in the order of 300 to 10,000 mg/l. Receiving stream concentrations will be intermediate dependent upon the degree of dilution. Sulfate analysis of samples collected in the Potomac Basin were analysed colorimetrically using barium chloranilate.

8. Hardness - E.D.T.A. titration hydroxy napthol blue indicator.

This procedure measures the total concentration of such ions as calcium, magnesium, lithium, etc. It does not differentiate between species.

Unpolluted waters usually exhibit lower values in the order of 100 mg/l as $Ca\ CO_3$ as compared to mine drainage 500 to 2,000 mg/l as $Ca\ CO_3$.

9. Calcium - by E.D.T.A. titration - Eriochrome Black T Indicator or by Atomic Absorption.

This procedure measures only the concentration of calcium, a component of hardness.

Concentrations of this indicator in unpolluted waters are in the order of 15 to 30 mg/l.

10. Magnesium - by Atomic Absorption.

This procedure measures only the concentration of magnesium, which is also a component of hardness. Concentrations of this indicator in unpolluted water are in the order of 10 to 20 mg/l.

11. Manganese - by Atomic Absorption.

This procedure measures the concentration of manganese, normally an acidic precursor. Concentrations in natural streams do not usually exceed 0.05 mg/l. This indicator is usually associated with coal-bearing strata and resultant mine drainage pollution. Concentrations in the order of 5 mg/l to 20 mg/l are not uncommon in mine drainage.

12. Aluminum - by Colorimetric determination.

This indicator, a potential acidic precursor, is usually present in rather low concentrations in unpolluted water. High concentrations are usually found as a result of the leaching of deposits of clays associated with the coal-bearing strata by the acid mine drainage.

13. Iron - Ferrous and Total by 1,10 Phenanthroline (SFS modification of Standard Methods-12th Edition).

Generally mine drainage pollution contains iron in both the ferrous and ferric states. Ferric iron does not contribute to acidity. Ferrous iron, a major contributor to acidity, is usually present in high concentrations in active mine drainage discharges. The presence of ferrous iron in a receiving stream usually indicates that the reactions have not gone to completion. The ferric iron present in systems above a pH of 3 is in the particulate state.

In receiving streams, measurements of the total iron concentration are complicated by sampling problems, since the amount of ferric iron present is dependent upon the stream velocity and sampling depth.

Unpolluted streams in the Basin have iron concentrations frequently less than 0.3 mg/l. Mine drainage influence may raise iron concentrations to in excess of 100 mg/l.

X. SUB-BASIN DESCRIPTION

A. West Branch Susquehanna River

1. Introduction

The West Branch Susquehanna River drains an area of 6,913 square miles in the west central portion of the Susquehanna River Basin. The Basin lies entirely within Pennsylvania and includes all or portions of 19 counties: Cambria, Clearfield, Centre, Elk, Cameron, Potter, Clinton, Columbia, Tioga, Indiana, Jefferson, Lycoming, Bradford, McKean, Sullivan, Montour, Northumberland, Union, and Wyoming. The Basin is bounded on the north by the Genesee and Chemung River Basins, on the south by the Juniata River Basin, on the east by the Susquehanna River Basin and on the west by the Allegheny River Basin. The West Branch Susquehanna River has its source in northwestern Cambria County and flows a distance of 240 miles to its confluence with the Susquehanna River at Northumberland, 123.5 miles from its mouth.

The upper portion of the Basin lies within the high tablelands of the Appalachian Plateau Province. At Lock Haven the river breaks through the Allegheny Front, the escarpment which divides the Appalachian Plateau and Ridge and Valley Provinces, then flows approximately 70 miles through the Ridge and Valley Province to its confluence with the Susquehanna River. The Basin is approximately equally divided between the

Appalachian Plateau and Ridge and Valley Provinces. In the Appalachian Plateau Province, stream valleys are narrow and are flanked by high, steep hills. In the Ridge and Valley Province, valleys are generally broad and fertile and are bounded by rugged forested mountains. Moderate to steep gradients of streams in the Appalachian Plateau Province provide considerable turbulence and excellent mixing characteristics. The combination of low gradient and a wide, shallow channel configuration combine to produce poor mixing characteristics in the Ridge and Valley Province.

Major tributaries of the West Branch, their drainage areas and the mile point of their confluence with the main stream are tabulated in the following table:

Name	Drainage Area (square miles)	Mile Point of Confluence
Loyalsock Creek	493	35.2
Lycoming Creek	276	41.3
Pine Creek	973	67.6
North Bald Eagle Creek	782	67.7
Kettle Creek	239	104.1
Sinnemahoning Creek	1,033	110.2
Moshannon Creek	288	135.5
Clearfield Creek	396	171.5
Chest Creek	132	205.3

Figure 1-A is a map of the West Branch Susquehanna River Basin, illustrating major tributaries and other pertinent physical features.

2. Geology

Consolidated rocks which outcrop in the area are all of the Paleozoic era and are generally those of the Pennsylvanian and Mississippian systems. In descending order, the specific rock formations are identified as: Conemaugh, Allegheny, Pottsville, Mauch Chunk Shale, Pocono, Oswago and Catskill. Of these, only the Conemaugh and the Allegheny formations contain coal beds of economic significance.

A portion of the main Pennsylvania Bituminous Field lies within the Basin underlying all or a portion of Clearfield, Cameron, Clinton, Centre, Lycoming, Potter, Cambria, Indiana, McKean, and Elk Counties. The bituminous coal beds lie within the Appalachian Plateau Province in the western part of the Basin - (See Figure 1-A). Other coal deposits underlie portions of Blair, Huntingdon, Bedford, Fulton, Bradford, Tioga, and Sullivan Counties.

3. Economy

The rich bituminous coal deposits of the Pennsylvanian system play a dominant role in the area economy. It is estimated that approximately 4,400 (2) mines have been opened in the Basin, most of which have long been abandoned. Estimates by watershed as of 1962 (2) indicate the opening of about 830 mines in the Moshannon Creek watershed, 1,150 in the Clearfield Creek watershed, 330 in the Bennett Branch Sinnemahoning Creek watershed and 180 in the Beech Creek watershed. The remaining mines were opened in the watersheds of minor tributaries to the West Branch upstream from the mouth of Loyalsock Creek.

Of the original bituminous coal reserves in the sub-basin estimated to be 4,140 million tons in 1928 (3), about 2,535 (4) million tons still remained as "recoverable reserves" in January 1963. About 431 million tons of the depletion of the reserves is attributed to production (5). The remainder is considered "loss in mining", pillers, fines, unminable coal, etc. An estimated 1,334 million tons, more than half of the recoverable reserves, underlie Clearfield County (4). Coal production in the Basin has been relatively stable, averaging about 9 million tons per year since 1945. Recently Clearfield and Centre Counties have accounted for about 80 per cent of the production in the Basin (6).

Prior to 1945, deep mines accounted for most of the coal production in the Basin; however, development of large earth-moving equipment during World War II greatly stimulated surface mining activity. Strip mining accounted for 45 per cent of the Susquehanna River Basin's production in 1945 and 77 per cent in 1955 (6). Of the 8,650,000 tons of coal produced in 1962, about 84 per cent was mined at strip operations. Clearfield County produced 83 per cent of its total from strip mines (2). Strip mine production in the remaining coal producing counties exceeded 90 per cent of the total production.

Basin production for 1970 is projected at about 8,040,000 short tons. A gradual increase in production to 13,380,000 short tons in 2020 is expected (6). The following table lists projected bituminous coal production for the West Branch Susquehanna River Basin:

Projected Production of Bituminous Coal by Economic Subregion (6)

(thousands of short tons)

Economic Subregion	1970	1985	2020
Clinton Centre Lycoming	960	530	450
Cameron Clearfield	7,080	8,610	12,930
Total	8,040	9,140	13,380

4. Sub-Basin Description

A detailed discussion of the mine drainage sources in the Basin, their effect on stream quality and possible abatement methods follow:

a. Headwaters to Chest Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

A total of 88 major mine drainage discharges have been located in this sub-basin, contributing approximately 70,000 lbs/day net acidity. Most of the mine drainage originates in abandoned mines.

The first major addition of mine drainage in this reach enters in the form of a pumped discharge from an active deep mine. The discharge contributed a loading of 4,100 lbs/day net acidity during the sampling period. This contribution is primarily responsible for the mean acidity concentration of 450 mg/l and an associated loading of 4,800 lbs/day net acidity recorded at the first project sampling point on the West Branch about two miles downstream (See Figure 2).

Within the next seven miles, the river gains an additional 14,000 lbs/day net acidity; however, the net acidity concentration declines to 200 mg/l.

Major mine drainage contributors in the reach include three spoil piles and four abandoned deep mines. Their total contribution is 30,000 lbs/day net acidity. The three spoil piles were responsible for about 30 per cent of this total at the time of sampling.

Between Mile 229 and 220 the acid load is reduced by about 10,000 lbs/day and the acidity concentration declines to 50 mg/l. The responsible sources of alkalinity are not yet known; however, the reduction is probably the result of the neutralizing action of naturally alkaline tributaries to the reach. Several of these tributaries had alkalinities in excess of 150 mg/l during the survey period.

From Mile 220 to its confluence with Chest Creek, the West Branch did not exhibit a significant change in alkalinity during the survey period, although a slight increase in other mine drainage indicators was evident.

In general, concentrations of mine drainage indicators declined throughout the length of the reach from the headwaters to Chest Creek. Mean iron and manganese concentrations, which were 120 and 3.6 mg/l, respectively, at the head of the reach, declined to 1.1 and 2.5 mg/l, respectively. Sulfates declined from 1,300 mg/l to 550 mg/l (See Figure 2-A).

(2) Abatement and Control Measures

Abatement and control of mine drainage pollution in the sub-basin will involve reclamation of areas disturbed by strip mines, flooding of deep mines, restoration of drainage presently impeded by refuse banks, and possibly treatment.

Diversion of streams presently seeping through refuse banks would appear to be the most immediately effective and least costly abatement activity in this sub-basin. This work could be expected to reduce the acid loading on the West Branch by about 30 per cent in the reach from Mile 239 to Mile 229.

Research presently being conducted by the Barnes and Tucker Coal Company into the blending of acid and alkaline mine waters may result in the development of a relatively inexpensive method of reducing acid contributions from the Company's active mines, one of which contributed about 10 per cent of the acid contributed to this reach of the West Branch during the survey period.

b. Chest Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

Chest Creek, during the survey period, contributed approximately 2,500 lbs/day net alkalinity to the West Branch. Preliminary reconnaissance data indicate that, although the stream is alkaline at its mouth, a 3-mile reach is degraded by mine drainage originating in the watershed of Brubaker Run. Mining activity has been very heavy in the Basin. Sources of mine drainage include both deep and strip mines and refuse piles. Acid loads on the order of 1,000 lbs/day from Brubaker Run degrade the quality of Chest Creek from its confluence with Brubaker Run to Westover. At Westover a large alkaline discharge from a tannery adds significantly to the stream's alkalinity assets. Although the stream is alkaline downstream from Westover, significantly high levels of other mine drainage indicators were measured.

Active mining operations in the Brubaker Run watershed were greatly curtailed in March 1967. Although detailed location characterization work has not been completed in the sub-basin, it is believed that discharges from active mines contributed a significant portion of the mine drainage loading to Brubaker Run. The effect on stream quality of the closing of the active mines cannot be estimated at present.

(2) Abatement and Control Measures

Abatement of mine drainage pollution in the Brubaker Run watershed will involve an extensive program of deep and strip mine reclamation and treatment.

Because of the very intense mining activity that has taken place in the watershed and the absence of any known use of Brubaker Run, initial abatement efforts should probably be directed toward reducing the mine drainage load to the extent that Brubaker Run does not degrade the quality of the receiving stream, Chest Creek. Abatement work in the watershed should, however, be held in abeyance until the effect of the closing of active mines is fully determined.

c. West Branch Susquehanna River-Chest Creek to Clearfield Creek (not inclusing Anderson Creek)

(1) Mine Drainage Sources and Their Effect on Stream Quality

Only two significant mine drainage discharges were located in this Sub-Basin. Both discharges, with a combined loading of 2,300 lbs/day net acidity, originate in abandoned drift mines.

The West Branch Susquehanna River is essenially neutral in the reach from Chest Creek to Anderson Creek. The reach varies between weakly acid and weakly alkaline, depending upon hydrologic conditions. The minor tributaries to this reach, although in general slightly influenced by mine drainage, contribute alkalinity. Acid contributions by Anderson Creek, Montgomery Creek, and Wolf Creek, totaling about 3,100 lbs/day, were outweighed by alkaline contributions within the reach.

The pH within the reach ranged from 3.1 to 7.6. The mean total iron concentration declined from 1.1 mg/l to 0.25 mg/l through the reach. Manganese and sulfate concentrations declined from 2.5 mg/l and 553 mg/l, respectively, to 0.05 mg/l and 270 mg/l, respectively. Fish and other aquatic life have been observed in this reach, although the population is probably somewhat depressed by residual amounts of mine drainage.

(2) Abatement and Control Measures

Although mine drainage pollution abatement work in this Sub-Basin should be included in a comprehensive program of pollution abatement in the West Branch Susquehanna River Basin, the work should probably have low priority in view of the relatively minor effect on the receiving stream.

The recently-completed Curwensville Dam, a multi-purpose structure controlling the West Branch immediately upstream from Anderson Creek, might profitably be employed in a comprehensive pollution abatement and control program by providing flow regulation for water quality control.

Cooperative studies are presently underway to determine the effect of impoundment on water quality in the reservoir.

d. Anderson Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

Anderson Creek contributed an average of 1,750 lbs/day net acidity to the West Branch during the survey period. Most mining activity has been confined to the lower reaches of the watershed, and stream quality is not seriously impaired by mine drainage upstream from the confluence with Little Anderson Creek. (See Figure 1-A) Downstream from Little Anderson Creek, the stream is rendered acid by mine drainage which is tributary to Little Anderson Creek. Minor tributaries from the right downstream from Little Anderson Creek add to the acid loading of Anderson Creek.

Mean total iron, manganese, and sulfate concentrations measured at the mouth were 3.9 mg/l, 3.4 mg/l and 160 mg/l, respectively.

Most of the mine drainage in the watershed originates in abandoned mines. Although 28 discharges were observed, about 70 per cent of the acid load measured originates at five discharges.

(2) Abatement and Control Measures

Mine drainage pollution abatement in this watershed will require surface reclamation, mine flooding and possibly treatment. Two drift mine discharges close to the Little Anderson Creek watershed discharge an acid loading approximately equal to the net acid loading at the mouth of Anderson Creek. Abatement of the polluting properties of these discharges, through sealing or treatment accompanied by relatively minor abatement work at other discharge points, could reduce the acid load to a level at which Anderson Creek could probably assimilate the residual under most flow conditions.

e. Clearfield Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

Clearfield Creek is rendered acid by mine drainage from its source to its mouth. During the survey period, the stream contributed an average of 57,000 lbs/day acidity to the West Branch.

At the mouth, mean net acidity concentrations of 115 mg/l were measured. Total iron concentrations were relatively low (1.4 mg/l); however, other mine drainage indicators were present in high concentrations.

Although mining activity has been very extensive throughout most of the watershed, about 45 per cent of the acid load in Clearfield Creek originates in 10 tributaries which have a combined drainage area of 95 square miles, or about 25 per cent of the area of the Clearfield Creek watershed.

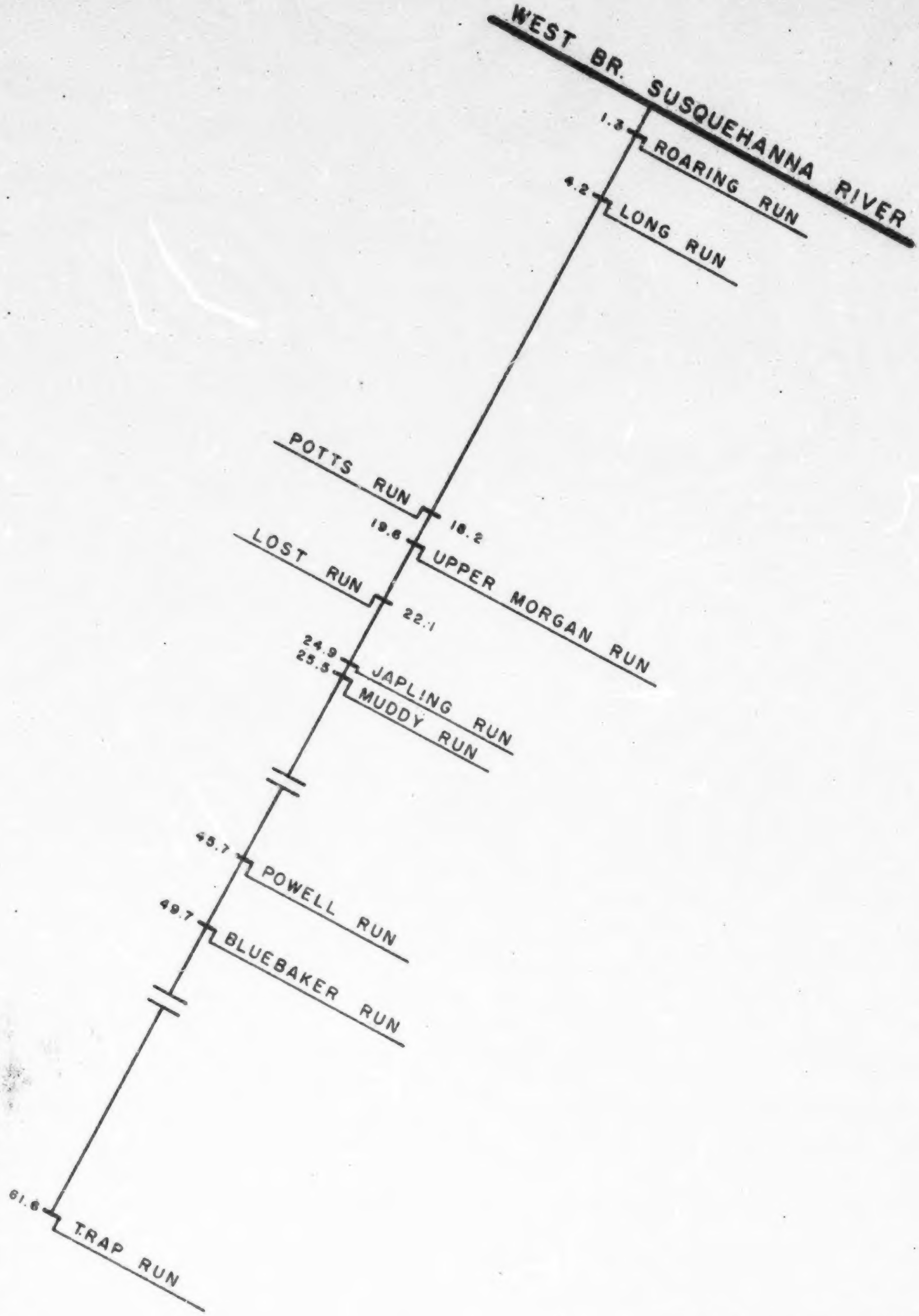
The streams responsible for most of the acid load in Clearfield Creek are shown in the following schematic diagram and tabulation:

PRINCIPAL DRAINAGE CONTRIBUTORS TO CLEARFIELD CREEK

STREAM	STREAM MILE (on Clearfield Creek)	DRAINAGE AREA (Sq. Mile)	NET ACID LOADING (lbs/day)
Roaring Run	1.3	12.2	550
Long Run	4.2	4.0	960
Potts Run	18.2	15.4	3,180
Upper Morgan Run	19.6	12.2	760
Lost Run	22.1	2.5	3,180
Japling Run	24.9	3.2	3,900
Muddy Run	25.5	30.6	6,500
Powell Run	45.7	11.2	2,280
Brubaker Run	49.7	2.5	920
Trap Run	61.6	1.5	1,210

Seventy-eight major mine drainage discharges were located in the Sub-Basin. Field analysis of the discharges indicated that 16 of these major discharges, with a combined flow of 11 cfs, contributed about 30,000 pounds acidity per day, or about 60 per cent of the acid load at the mouth.

Most of the major discharges are recorded as discharges from strip mine areas; however, they are in many cases a


WEST BR. SUSQUEHANNA RIVER
1.3
ROARING RUN
4.2
LONG RUN
POTTS RUN
18.2
19.6
UPPER MORGAN RUN
LOST RUN
22.1
24.9
25.5
JAPLING RUN
MUDDY RUN
45.7
POWELL RUN
49.7
BLUEBAKER RUN
61.6
TRAP RUN

25.5 – INDICATES RIVER MILES

CLEARFIELD CREEK

SCHEMATIC DIAGRAM OF STREAMS AFFECTED BY MINE DRAINAGE POLLUTION combination of drainage from both deep and strip mines. Since in many cases strip mines have intercepted shallow deep mines or crossed deep mine portals, it is particularly difficult in this Sub-Basin to differentiate between deep and strip mine drainage. Essentially all the acid drainage located in the Sub-Basin is discharged from abandoned mines.

(2) Abatement and Control Measures

Extensive disturbed areas, large numbers and varieties of mine drainage sources, and heavy acid loadings combine to make Clearfield Creek one of the most difficult streams in the Study Area to reclaim.

Survey data indicate that reclamation work in the watersheds of the 10 tributaries found to be contributing most of the acid drainage would reduce the mine drainage load in Clearfield Creek. Although complete restoration of the quality of Clearfield Creek might not be attainable in the immediate future, any reduction in the mine drainage loading to tributaries of Clearfield Creek will have a beneficial effect on the quality of Clearfield Creek and the West Branch Susquehanna River. Because of the extensive work required in this Sub-Basin to produce a measurable improvement in the quality of Clearfield Creek, pollution abatement work should perhaps be undertaken only in conjunction with a comprehensive mine drainage pollution abatement program aimed at restoring the quality of all streams in the West Branch Susquehanna River Basin or a very limited project intended to abate pollution in a tributary of Clearfield Creek.

f. West Branch Susquehanna River-Clearfield Creek to Moshannon Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

The quality of the West Branch in this reach is seriously degraded by mine drainage contributed by Clearfield Creek and several minor tributaries within the reach. As shown in Figure 2, acid loadings increase from about 4,000 lbs/day net alkalinity at Mile 173 upstream from Clearfield Creek to 53,000 lbs/day net acidity at Mile 163 about 9 miles downstream from Clearfield Creek. The acidity concentration both upstream and downstream from Clearfield Creek was about 50 mg/l during the sampling period. The acid load increased to about 108,000 lbs/day at Mile 144, upstream from Moshannon Creek, the result of acid contributions from minor tributaries. Iron and manganese concentrations of 6 and 7 mg/l, respectively, were common (See Figure 2-A).

Significant contributors of mine drainage sampled include the following streams: Lick Run, Trout Run, Millstone Run, Surveyor Run, Murray Run, Congress Run, Deer Run, Sandy Creek, and Alder Run. The total acid contribution by the nine streams was about 40,000 lbs/day. Location and characterization of mine drainage discharges in these stream basins has not been completed. It is believed, however, that most of the drainage originates in abandoned deep mines, with a somewhat lesser amount originating in abandoned strip mines.

(2) Abatement and Control Measures

Since the sources of mine drainage in this watershed have not been located, no definite statement on abatement methods can be made. The nine minor tributary sub-basins do, however, contribute a very significant portion of the mine drainage load to the West Branch and should be included in any comprehensive mine drainage pollution abatement program.

g. Moshannon Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

Moshannon Creek is the largest contributor of mine drainage to the West Branch Susquehanna River. During the survey period the stream contributed an average of about 130,000 lbs/day net acidity to the West Branch.

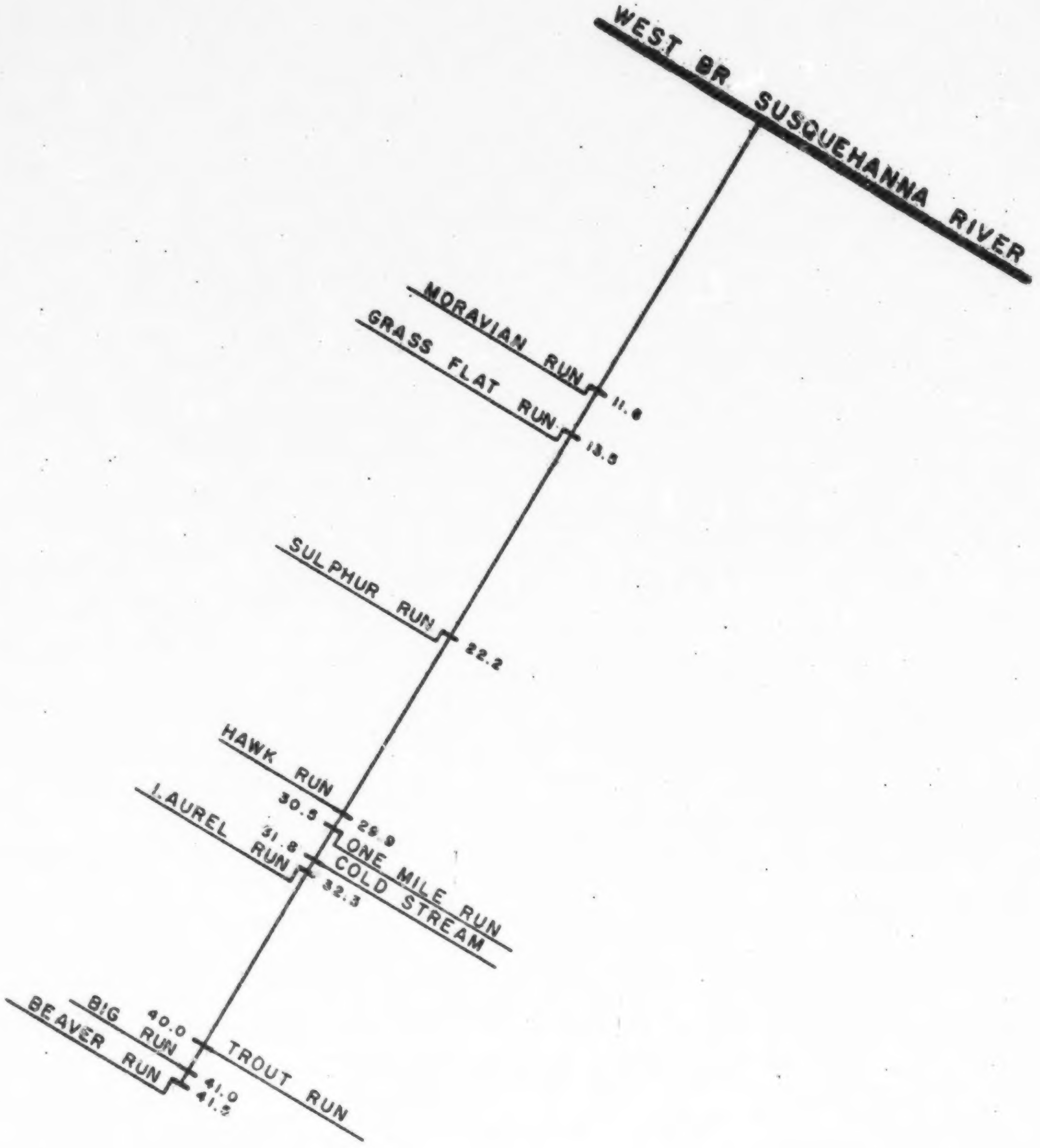
Stream quality at the mouth is fairly representative of stream quality throughout most of its length. Mean net acidity was 228 mg/l. Iron and manganese concentrations were 15.3 mg/l and 7.6 mg/l, respectively, during the survey period.

As in the Clearfield Creek Sub-Basin, mining has been accomplished over most of the Sub-Basin both by surface and subsurface methods. The quality of most of the streams in the watershed is influenced by mine drainage to some degree. A survey conducted in 1964 located 50 tributaries which were contributing acid to Moshannon Creek. The 10 streams listed in the following table are considered to be the most significant contributors of mine drainage:

PRINCIPAL MINE DRAINAGE CONTRIBUTORS TO MOSHANNON CREEK

STREAM	STREAM MILE (on Moshannon Creek)	DRAINAGE AREA (Sq. Mile)	NET ACID LOADING (lbs/day)
Moravian Run	11.6	1.8	820
Grass Flat Run	13.5	1.0	4,970
Sulphur Run	22.2	2.3	14,360
Hawk Run	29.9	2.4	19,540
One Mile Run	30.5	0.5	8,270
Cold Stream	31.8	23.6	1,980
Laurel Run	32.3	19.5	5,870
Trout Run	40.0	11.0	29,650
Big Run	41.0	2.5	2,080
Beaver Run	41.5	19.0	1,980

The following figure is a schematic representation of the principal mine drainage contributors to Moshannon Creek.


WEST BR. SUSQUEHANNA RIVER
MORAVIAN RUN
11.8
GRASS FLAT RUN
13.5
SULPHUR RUN
22.2
HAWK RUN
30.5
29.9
ONE MILE RUN
LAUREL RUN
31.8
COLD STREAM
32.3
BIG RUN
40.0
TROUT RUN
BEAVER RUN
41.0
41.5

25.5 - INDICATES RIVER MILES

MOSHANNON CREEK

SCHEMATIC DIAGRAM OF STREAMS AFFECTED BY
MINE DRAINAGE POLLUTION

X-17-B

One hundred and thirty-three discharges contributing about 144,000 lbs/day acidity have been located in the Sub-Basin. Of the 133 discharges, 32 contributed most of the acid load. Preliminary information indicates that one discharge contributes about 29,000 lbs/day acidity, or about 20 per cent of the acid load in Moshannon Creek at the mouth. As in the Clearfield Creek Sub-Basin, essentially all of the mine drainage in this watershed originates in abandoned mines, and many discharges are a combination of deep and strip mine drainage.

(2) Abatement and Control Measures

Because of very extensive mining activity over most of the Sub-Basin and the resultant large mine drainage load, the Moshannon Creek watershed is the key to the success of any comprehensive mine drainage pollution abatement and control program in the West Branch Basin.

Any comprehensive program in the Moshannon Creek watershed would, however, be very costly. Considerable reduction in the acid loading in Moshannon Creek could be attained by reclamation of several of the 10 major contributing streams and/or by providing treatment of some of the 32 largest discharges.

Detailed engineering studies in the Sulphur Run watershed are being accomplished by a consulting engineer under contract with the Chesapeake Bay-Susquehanna River Basins Project. The consultant will determine appropriate methods and the attendant costs of mine drainage pollution abatement. This study, one of five sponsored by the Project, will serve to further refine estimated costs of mine drainage pollution abatement throughout the Bituminous Coal Fields.

h. West Branch Susquehanna River-Moshannon Creek to Sinnemahoning Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

In this reach the quality of the West Branch is severely degraded by mine drainage contributed in upstream reaches and by Moshannon Creek. Acid concentrations and loadings vary slightly within the reach; however, the variations are not considered significant. Mean net acidity during the survey was about 130 mg/l. Sulfate concentrations were in the 800 to 1,000 mg/l range.

Most of the minor tributaries to this reach are mildly acid or mildly alkaline and have no significant effect on the quality of the West Branch.

Mine drainage location and characterization work has not been completed in this watershed; however, it is known that a limited amount of mining has been accomplished.

(2) Abatement and Control Measures

Minor tributaries to the West Branch in this reach lie in a remote, almost inaccessible area. It is believed that most of the mine drainage contributed in this Sub-Basin originates in abandoned deep mines. Abatement work would have very little effect on any streams with significant public use or on the quality of the West Branch.

Work in this Sub-Basin should probably have low priority.

i. Sinnemahoning Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

During the study period Sinnemahoning Creek contributed about 36,000 lbs/day net acidity to the West Branch. The Creek, with its drainage area of 1,032 square miles, has the largest watershed area tributary to the West Branch. It encompasses approximately 40 per cent of the area of the West Branch Basin at their confluence. Major tributaries include the First Fork Sinnemahoning, Bennett Branch Sinnemahoning, and Driftwood Branch Sinnemahoning.

Although the stream has a large watershed area, topographic and geologic conditions combine to produce "flashy" flow characteristics with low drought flows and low natural alkalinity reserves in the stream. These characteristics combine to give it a very poor capacity to assimilate mine drainage discharges.

Although most of the watershed lies within the Bituminous Coal Fields, mining activity has been restricted almost exclusively to the watersheds of the Bennett Branch Sinnemahoning and Sterling Run, a minor tributary to the Driftwood Branch Sinnemahoning. The Bennett Branch is essentially acid from its source to its mouth. It, in turn, renders Sinnemahoning Creek acid from their confluence to its mouth. Sterling Run, while not overcoming the alkalinity reserve in the Driftwood Branch, does add mine drainage indicators.

Although quite acid (136 mg/l net acidity), the Bennett Branch is relatively low in concentrations of other mine drainage indicators. The mean total iron and manganese concentrations were, for example, only 1 mg/l and 4.1 mg/l, respectively, during the survey period. Concentrations of most mine drainage indicators at the mouth of Sinnemahoning Creek are about half of Bennett Branch concentrations, reflecting the "diluting" effect of other tributaries of Sinnemahoning Creek.

Mine drainage discharge location and characterization work has not been completed in this Sub-Basin; however, preliminary reconnaissance indicates that most of the mine drainage originates in abandoned deep mines. The make of the mines is, however, significantly influenced by strip mining operations. Preliminary information indicates that the discharges from four tributaries to the Bennett Branch may equal the acid loading in the Sinnemahoning Creek at its mouth.

(2) Abatement and Control Measures

Data available at this time indicate that abatement work in this watershed would involve surface reclamation, inundation, and treatment.

The Pennsylvania Coal Research Board has contracted with the Pennsylvania State University to design a 4 mgd lime neutralization plant to treat a large discharge near the Village of Hollywood, which is near the source of the Bennett Branch. The plant, intended as a demonstration project, will neutralize that which is reputed to be the largest acid discharge in the watershed.

The George B. Stevenson Dam, a flood control reservoir which controls a portion of the First Fork Sinnemahoning watershed, might profitably be utilized for flow regulation for water quality control in a comprehensive pollution abatement program. The low natural alkalinity in the impounded water tends, however, to limit the utility of this water.

j. Kettle Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

Kettle Creek, with its contribution of 15,000 lbs/day acidity during the survey period, is the most downstream direct source of mine drainage to the West Branch. Throughout most of its length, Kettle Creek flows through heavily forested land and is considered an excellent trout stream. In its lower 2 miles, its naturally low alkalinity is overcome by mine drainage contributed by Two Mile Run and discharges which enter directly.

Mine drainage discharge location and characterization work has not been completed in this Sub-Basin; however, it is believed that the mine drainage originates in abandoned surface and subsurface mines.

(2) Abatement and Control Measures

Abatement work in this Sub-Basin will probably require an extensive surface reclamation and deep mine inundation program coupled with treatment and/or conveyance of mine drainage directly to the West Branch.

A portion of the Sub-Basin is controlled by the Alvin C. Bush Dam, a flood control structure. The naturally low alkalinity of the impounded water limits its utility for water quality control purposes.

k. North Bald Eagle Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

North Bald Eagle Creek is responsible for neutralizing most of the acid load in the West Branch. Its contribution of 132,000 lbs/day alkalinity during the survey period was the largest single source of alkalinity to the West Branch.

Considerable mining has taken place in the Sub-Basin, however, and the quality of the lower reaches of North Bald Eagle Creek is influenced by mine drainage. Essentially all the mining in the Sub-Basin has been accomplished in the watershed of Beech Creek, a major tributary. Beech Creek is acid from its source to its mouth and contributed about 10,000 lbs/day net acidity to North Bald Eagle Creek during the survey period. Under most natural flow conditions, the alkalinity in North Bald Eagle Creek is adequate to neutralize the acid contributed by Beech Creek. During periods of unbalanced rainfall and runoff in the Sub-Basin, high flows from Beech Creek have significantly reduced the alkalinity in North Bald Eagle Creek. Flow regulation by Blanchard Dam, a multi-purpose structure now under construction immediately upstream from Beech Creek, may tend to accentuate this condition.

Mining conditions in the Beech Creek watershed are very similar to those in the nearby Clearfield and Moshannon Creek watersheds. Much of the watershed has been mined, both by surface and sub-surface methods. Although more than a hundred mine drainage discharges have been located in the watershed, preliminary evaluation of the data indicates that most of the acid originates in six major discharges.

(2) Abatement and Control Measures

A combination of almost all abatement methods will probably be applicable in this Sub-Basin. Abatement work should have a high priority, since reduction of acid loadings is needed to protect the quality of North Bald Eagle Creek during periods of unbalanced streamflow caused by natural conditions and by flow regulation by the Blanchard Dam.

A project in the Beech Creek watershed intended to reclaim 379 acres in the Sproul State Forest is in the late-planning stages. This project, to be financed with Appalachia Funds, is expected to affect some stream quality benefit.

1. West Branch Susquehanna River-Sinnemahoning Creek to Mouth

(1) Mine Drainage Sources and Their Effect on Stream Quality

As shown in Figure 2, the quality of the West Branch in this reach varies significantly in response to several major inputs.

Acid contributed by Sinnemahoning Creek was responsible for a 15,000 lbs/day net acidity increase in the acid load in the river from Mile 111 to Mile 105 during the survey period. The contribution of an additional 15,000 lbs/day acidity by Kettle Creek further increased the acid loading at Mile 98. Although acid concentrations do not vary appreciably between Kettle Creek and North Bald Eagle Creek, net acidity loadings increase with increases in flow at successive sampling stations. The apparent increase in loading is believed to be primarily the result of limitations in the precision of analysis and flow measurement procedures, and not to mine drainage discharges in the reach.

At Mile 68 (Lock Haven), North Bald Eagle Creek, with its contribution of 132,000 lbs/day net alkalinity during the survey period enters the West Branch and contributes most of the alkalinity required to neutralize the acid load in the West Branch. Other major alkaline tributaries in the reach between Mile 68 and Mile 040 (Williamsport) which contribute to the neutralization of the West Branch include Pine Creek, Larry's Creek, Lycoming Creek, and Antes Creek.

Downstream from Williamsport, the West Branch is normally weakly alkaline (10 mg/l net alkalinity) and receives no direct mine drainage discharges. During unusual flow conditions, when the ratio of the flow in the West Branch to the flow in North Bald Eagle Creek is considerably higher than normal, the acid load carried by the West Branch is not neutralized, and acid conditions prevail downstream from Williamsport, sometimes to the mouth. This condition frequently occurs in late summer in conjunction with heavy rains in the Clearfield and Moshannon Creek watersheds with no corresponding rainfall in the North Bald Eagle Creek watershed. The condition, normally a once-yearly occurrence, causes extensive fish kills downstream from Williamsport.

(2) Abatement and Control Measures

No significant mine drainage sources which discharge directly to the West Branch have been located in this reach, except those which are described in the discussion of major sub-basins.

Flow regulation to control the chronic "acid slug" condition may be possible if greater utilization of the water quality control capability of existing flow regulation structures and more timely information on water quality and flow conditions can be attained.

Blanchard Dam, now under construction on North Bald Eagle Creek, would probably be the key to any program of flow regulation for water quality control. The high alkalinity of the impounded water (110 mg/l during the survey period) will make it by far the most promising source of "stored alkalinity" in the Basin.

m. Loyalsock Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

Although Loyalsock Creek is an alkaline stream at its mouth and bears no significant evidence of mine drainage indicators throughout most of its length, it does receive mine drainage from abandoned mines in an isolated semi-anthracite deposit in the headwaters.

Two drainage tunnels near the Village of Lopez (See Figure 1-A) discharge mine drainage with a net acidity concentration of approximately 60 mg/l. The addition of this slightly acid discharge to the stream, which has a naturally low residual alkalinity, causes degradation for approximately eight miles downstream.

(2) Abatement and Control Measures

One method of abating polluting discharges in this Sub-Basin would be to remove all of the remaining coal in the Sub-Basin, using surface mining methods. Restoration of the stripped area would probably abate the polluting discharges.

Because of the relatively small mine drainage loading and the great effect on stream quality, considerable benefit could be attained by relatively low cost abatement measures. This area should have a high priority for future abatement work.

B. Juniata River Basin

1. Introduction

The Juniata River, 86 miles long with a drainage area of 3,406 square miles, is formed by the junction of the Little Juniata River and Frankstown Branch Juniata River in Huntingdon County, 3.5 miles southeast of Huntingdon, Pennsylvania. The stream flows easterly by a circuitous route to its confluence with the Susquehanna River.

All of Blair and Huntingdon Counties are located within the confines of the Basin. Also included are portions of Bedford, Centre, Fulton, Mifflin, Juniata, and Perry Counties. Figure 1-B is a map showing major streams and other pertinent features of the Basin.

2. Geology

Virtually the entire Juniata River Basin lies within the "Ridge and Valley" Province. This area is characterized by an alternate succession of long ridges and valleys, generally oriented from southwest to northeast. The ridges comprising the western part of the Basin are steep and rugged, whereas, the eastern part is considerably more rolling in nature. A small area on the western edge of the Basin drains a part of the Appalachian Plateau Province.

Extremes in elevation range from 340 to 2,900 feet above mean sea level.

Forests occupy approximately two-thirds of the total watershed and, for the most part, cover the higher ridges and mountains. Farmland is predominantly confined to the lower, more fertile valleys and encompasses approximately one-fourth of the Basin area.

The coal fields influencing stream quality are located in the southwestern portion of the watershed in Blair, Huntingdon, Bedford, and Fulton Counties. The largest coal deposit in the watershed is the Broad Top Coal Field, located in Bedford, Huntingdon, and Fulton Counties. The field, approximately 81 square miles in area, lies in a highly dissected plateau known as Broad Top Mountain and is east of the Allegheny Mountains, totally isolated from the main bituminous coal fields. The largest portion of the coal deposit and major producing area lies in the northeast corner of Bedford County. The remainder of the field lies in the southern end of Huntingdon County with an extension into the northwest corner of Fulton County.

A small portion of the main bituminous coal field lies within the watershed on the western edge of Blair County along the eastern slope of Allegheny Mountain.

3. Economy

The production of bituminous coal constitutes an important industry in the Juniata Basin, although no longer a major one. The first authenticated record of coal mining in the area occurred during the Revolutionary War when coal was mined for home use. The first commercial shipments were made in 1853, reaching a peak production of approximately 2.7 million short tons in 1918. By 1964 coal production had diminished to about 0.4 million short tons.

Projections of production in the Juniata Basin are as follows:

Projected Bituminous Production (Thousand Short Tons) (6)

1970	1985	2020
490	780	1,520

Reserves of coal have been estimated to total 215 million short tons of which approximately 129 million short tons are recoverable. (5)

4. Sub-Basin Description

Data collected during a reconnaissance and sampling program conducted by personnel of the Chesapeake Bay-Susquehanna River Basins Project in August 1965 indicate that mine drainage is contributed to four major tributaries of the Juniata River. The Little Juniata and Frankstown Branch are influenced primarily by active and abandoned mining operations in the coal measures along the eastern slope of Allegheny Mountain in western Blair County. The Raystown Branch and Aughwick

Creek receive mine drainage originating in the Broad Top Coal Field.

a. Little Juniata River

(1) Mine Drainage Sources and Their Effect on Stream Quality

Mining activity in this Basin has been limited almost exclusively to the Bells Gap Run watershed which has been extensively deep and strip mined.

Sampling of the Little Juniata River upstream from the confluence with Bells Gap Run indicated an initial net alkalinity of 100 mg/l accompanied by low level concentrations of other mine drainage indicators. Bells Gap Run, despite mine drainage contributions, exhibits very little evidence of mine drainage indicators at its mouth and contributes an alkaline loading of approximately 170 lbs/day to the Little Juniata River.

(2) Abatement and Control Measures

Mine drainage pollution abatement in this watershed will involve extensive restoration of areas disturbed by surface mining. Since the stream is used as a source of public water supply, it may prove economically feasible to provide treatment facilities such as ion exchange, which will produce a high quality water suitable for use as a public water supply.

b. Frankstown Branch Juniata River

(1) Mine Dranage Sources and Their Effect on Stream Quality

The Frankstown Branch exhibited an alkaline reserve of 110 mg/l net alkalinity at its confluence with the Little Juniata during the sampling period. The stream, while alkaline, contains significant levels of iron and hardness, mine drainage indicators.

The major contributor of mine drainage during the sampling period was the Beaver Dam Branch, which contributed approximately 3,000 lbs/day net acidity. The major sources of mine drainage to the Beaver Dam Branch were Burgoon Run and Sugar Run.

Burgoon Run receives mine drainage from Kittanning Run and Glenwhite Run, small streams whose watersheds have been almost completely disturbed by surface mining. Kittanning Run is diverted around a public water supply reservoir serving the City of Altoona and enters Burgoon Run downstream from the Reservoir. The flow of the upper reaches of Burgoon Run and the normal flow of Glenwhite Run form the reservoir supply. During periods of high runoff, however, the flow of Glenwhite Run is also diverted to the by-pass.

Sugar Run had an acid loading at its mouth of 1,000 lbs/day net acidity. Most of the acid originates in the discharge from one abandoned deep mine.

(2) Abatement and Control Measures

Mine drainage pollution abatement activities in this

Basin should be directed toward producing a water suitable as a source of public water supply. Altoona is in serious need of additional public water supply. Treatment of the mine drainage normally diverted around the reservoir would add appreciably to the city's supply. Ion exchange, or some other method which produces a high quality product, would be the most desirable treatment process.

Preliminary data collection activities are in progress on a demonstration project in the Glenwhite Run watershed, being carried out jointly by the FWPCA and the Bureau of Mines. Reclamation work carried out will, it is hoped, reduce the mine drainage effect on the quality of Glenwhite Run and reduce the need for by-passing the water supply reservoir during high flow periods.

Since one discharge is the primary source of pollution of Sugar Run, mine flooding and/or treatment would appear to be applicable abatement methods in that watershed.

c. Raystown Branch Juniata River

(1) Mine Drainage Sources and Their Effect on Stream Quality

Mine drainage in this Sub-Basin originates in the Broad Top Coal Field and is conveyed to the Raystown Branch by Longs Run, Six Mile Run, Shoups Run, and Great Trough Creek. Each of the first three streams is acid from its source to its mouth.

Great Trough Creek is acid throughout its length in the coal fields, approximately five miles. Alkaline tributaries neutralize the acid load and provide an alkaline reserve of 200 lbs/day at its mouth.

The three acid streams contributed the following acid loading to the Raystown Branch during the survey period:

Longs Run -- 5,600 lbs/day net acidity
Six Mile Run -- 2,800 lbs/day net acidity
Shoups Run -- 3,200 lbs/day net acidity

In spite of the sizable acid contributions, as shown in Figure 3, the alkaline reserve of Raystown Branch upstream (42,000 lbs/day during the sampling period) was more than ample to assimilate the acid contributed. The Raystown Branch downstream from the coal fields exhibited essentially no evidence of the mine drainage loading.

Water quality in the three acid streams was generally comparable. They had pH's of less than 4.5, and elevated concentrations of manganese, sulfate, hardness, and other mine drainage indicators. Inexplicably, the iron concentration in Shoups Run was normally less than 1 mg/l; while in Longs Run and Six Mile Run, mean concentrations exceeded 10 mg/l.

All of the mine drainage discharges located in the watersheds tributary to the Raystown Branch originated in deep mines. A limited amount of surface mining has taken place in the Basin and may be influencing deep mine discharges; however, no surface discharges were observed.

(2) Abatement and Control Measures

In view of the relatively minor effect of mine drainage on the quality of the Raystown Branch, abatement programs in the watersheds influenced by mine drainage might include conveyance of at least a portion of the mine drainage to the Raystown Branch, in addition to more conventional methods such as treatment, surface reclamation, and mine flooding.

The limited effect on existing water uses and on downstream water quality in the Raystown Branch suggest a low priority for abatement work in this Sub-Basin.

d. Aughwick Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

A small percentage of the Broad Top Coal Fields lies in the Aughwick Creek Sub-Basin. Roaring Run, a tributary of Sidling Hill Creek, which in turn is tributary to Aughwick Creek, is the only known contributor of mine drainage in the Sub-Basin. Roaring Run with its acid loading of 750 lbs/day during the sampling period degraded the quality of Sidling Hill Creek at their confluence. Alkalinity contributed by other tributaries enabled Sidling Hill Creek to recover from the acid loading and have an alkaline reserve at its mouth.

(2) Abatement and Control Measures

Most of the mine drainage contributed to Roaring Run originates in one discharge. Abatement of pollution from this source would have considerable value, reclaiming a number of miles of otherwise unpolluted streams.

C. Tioga River Basin

1. Introduction

The Tioga River originates in Armenia Township in western Bradford County. The drainage area (within Pennsylvania), 689.5 square miles, is contained in portions of Potter, Tioga, and Bradford Counties. The stream is 58 miles long, 45 miles of which are in Pennsylvania. It flows in a southwesterly direction into Tioga County near Blossburg, Pennsylvania, and thence in a northerly direction to join the Chemung River in New York State. Figure 1-C is a map of the portion of the Susquehanna River Basin which includes the Tioga River Basin.

2. Geology

Located within the Allegheny Plateau physiographic province, the Study Area is characterized by broad valleys and steep, rounded hills. Shale and sandstone, along with coal in the upper portion of the Sub-Basin, are the dominant geologic formations. Most of the stream channels are bordered by wide alluvial flood plains containing deposits of glacially-derived boulders and gravel.

Most of the alluvial valleys are devoid of tree cover. In contrast, the hills in the Sub-Basin are steep, rugged, uncultivated and heavily wooded.

Coal deposits in the Sub-Basin are located in the extreme headwaters of the stream and are contained in two canoe shaped synclinal basins. The first and most important, the Blossburg Basin underlying the Morris Run, Coal Creek, and Bear Creek watersheds, extends in a general northeast-southwest direction. The second, the Gaines Basin underlying the Johnson Creek watershed, is a few miles north of and approximately parallel to the Blossburg deposit. Of the four minable beds contained in the Basins, three have been or are being mined.

3. Economy

Historically, the mining of bituminous coal in the Area was the primary industry. Mining activity began in the 1840's reaching a maximum of approximately 1.4 million tons in 1886. Production has since declined to a level of approximately 0.4 million tons in 1964. Great emphasis is placed on surface mining. Approximately 80 per cent of the coal is produced by this method. Projections of production for the Tioga River Basin are shown in the following table:

Projected Bituminous Coal Production (Thousand Short Tons) (6)

1970	1985	2020
360	460	660

Reserves of coal have been estimated (5) at a total of 41 million short tons, with approximately 16 million short tons considered recoverable.

4. Sub-Basin Description

The results of the reconnaissance and sampling program conducted by personnel of the Chesapeake Bay-Susquehanna River Basins Project during September and October 1965 indicate the quality of the Tioga River above its confluence with Morris Run is not significantly affected by mine drainage. The stream is, in fact, classified as a trout stream by the Pennsylvania Fish Commission. Below this point, however, for a distance of more than 25 miles, the stream is rendered acid by mine drainage contributed by Morris Run, Coal Creek, Johnson Creek and Bear Creek. Downstream tributaries have weak alkalinity common to this Area, but succeed in neutralizing the acid load downstream from Crooked Creek. Biological studies indicate mine drainage inhibition of aquatic life downstream to the confluence with the Canisteo River, an additional 27 miles downstream.

The Corps of Engineers is planning a multipurpose dam and reservoir at the confluence of Crooked Creek and the Tioga River. The dam will impound both streams in separate impoundments. Mine drainage influence on the quality of the Tioga River impoundment will limit water uses. The mean net acidity at the dam site was 100 mg/l during the survey. Iron and manganese concentrations were 2.1 and 3.7 mg/l, respectively. The pH ranged from 3.7 to 4.1.

a. Johnson Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

Although Johnson Creek contributes a weak alkaline loading to the Tioga River, it does receive mine drainage from abandoned surface and sub-surface mines near the Village of Arnot. As shown in Figure 5, mine drainage contributed in the Arnot area overcomes the stream's alkalinity for a short distance. Mine drainage indicator concentrations are low in Johnson Creek downstream from Arnot. Two discharges with a total net acid loading of 300 lbs/day were determined to be the major mine drainage contributors in the watershed.

2. Abatement and Control Measures

A limited program of mine sealing and surface reclamation would probably substantially improve water quality in this watershed.

b. Morris Run, Coal Creek, and Bear Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

Although Morris Run, Coal Creek, and Bear Creek constitute individual sources of mine drainage to the Tioga River, they overlie a common coal deposit. Underground and surface mining has diverted surface and ground water from watershed to watershed. The three watersheds will, therefore, be discussed as a single mine drainage source to the Tioga River.

As illustrated in Figure 4, the total acidity discharge from the three streams exhausted the Tioga River's rather weak

Since the coal measures are isolated from the main bituminous field and cover an area of only about 10 square miles, abatement work could be accomplished without involving a large geographical area. The extensive degradation of the quality of the Tioga River resulting from mine drainage discharges in the watershed and its effect on uses of water impounded by the proposed Tioga River Dam should give the area a high priority in future abatement programs.

A consulting engineer under contract with the Chesapeake Bay-Susquehanna River Basins Project is presently making a detailed engineering study of methods and associated costs of mine drainage pollution abatement in the watersheds.

Because of the mine drainage influence on the quality of the water to be impounded in the proposed Tioga River Dam, discharge schedules should be designed to take full advantage of the neutralizing capacity of Crooked Creek. Flow regulation at the dam may be an effective method of minimizing mine drainage influence on water quality downstream.

D. Anthracite Area

1. Introduction

Anthracite coal deposits in the Study Area lie in four individual fields in Northeastern Pennsylvania (See Figure 1-D). The coal fields, underlying a total area of 529 square miles, are designated the Northern Field, Western Middle Field, Eastern Middle Field, and Southern Field.

All of the Northern Field lies within the Susquehanna River Basin. Approximately 50 per cent of the Eastern Middle Field, 90 per cent of the Western Middle Field, and 40 per cent of the Southern Field are drained by the Susquehanna River and its tributaries. The remainder of the fields drain to the Delaware River through its tributaries, the Lehigh and Schuylkill Rivers.

Major streams draining the Anthracite Area are as follows:

Name	Drainage Area (square miles)	Mile Pt. of Confluence
Susquehanna River Basin		
Lackawanna River	346	195
Nescopeck Creek	172	159
Catawissa Creek	155	143
Shamokin Creek	138	122
Mahanoy Creek	155	112

Name	Drainage Area (square miles)	Mile Pt. of Confluence
Mahantango Creek	164	102
Wiconisco Creek	116	96
Swatara Creek	567	60
Delaware River Basin		
Lehigh River	1,373	
Schuylkill River	1,916	

The Area includes portions of Dauphin, Schuylkill, Northumberland, Columbia, Luzerne, Lackawanna, Carbon, Monroe, and Pike Counties.

The Area lies entirely within the Ridge and Valley Province of the Appalachian Highlands, the principal feature of which is a series of canoe shaped valleys in which the anthracite fields are located. The ridges trend generally northeast-southwest with elevations varying from 1,400 to 2,700 feet.

2. Geology

All the rocks of the Area are of sedimentary origin and are of the Paleozoic age. They belong to the Carboniferous, Devonian, and Silurian systems, with one formation of the Ordovician System found locally. The Carboniferous System is sub-divided into the Pennsylvanian and Mississippian series. The Pennsylvanian Series is further sub-divided into the Post-Pottsville and Pottsville Formations.

The Post-Pottsville Formations found within the four fields contain the most economically important deposits of Pennsylvania anthracite coal. These formations consist of beds of sandstone, shale, fireclay, black carbonaceous slate, and beds of coal ranging from seams several inches thick to the great Mammoth bed which has a thickness, in areas, in excess of 60 feet. The anthracite-bearing formations contain from 12 to 26 minable coal beds which are separated by from a few feet to as much as 200 feet of intervening shale, sandstone and/or conglomerate. While several anthracite beds found in the Pottsville Formation are locally minable, the major production is from the Post-Pottsville Formation.

In the Northern Field, coal deposits are contained within a canoe-shaped syncline which has a flat bottom and steep sides which outcrop along the mountain ridges. The Field is about 62 miles long, 5 miles wide and covers an area of approximately 176 square miles.

At Ashley, south of Wilkes-Barre, Pennsylvania, the coal measures reach a depth of 2,100 feet and contain 18 workable strata, having a combined thickness of about 100 feet. A unique feature of the Northern Field is its separation into two coal basins, the Lackawanna and Wyoming, by a structural saddle (the Moosic saddle) near Old Forge, Pennsylvania.

The Eastern Middle Field, with an area of approximately 33 square miles, consists of a number of long, narrow coal basins trending east to west. These coal basins are separated by members of the Pottsville conglomerate which contain no anthracite. Most of the deposits lie above surface drainage level and are drained by tunnels driven expressly to provide gravity drainage to surface streams. Numerous mine openings, slopes, drifts, and short tunnels also provide drainage.

The Western Middle Field consists of a series of parallel, irregularly shaped coal basins covering an area of approximately 120 square miles. The Field, about 42 miles long and from two to five miles wide, contains strata which locally lie nearly horizontal or pitch steeply. Deposits resemble those in the Eastern Middle Field, except that most of the deposits lie below surface drainage level and are now flooded.

The Southern Field, about 70 miles long and 1 to 6 miles wide, covers an area of about 200 square miles. The Field consists of a series of basins, extending from Mauch Chunk on the west to the "fish tail" formed by a separation of the coal measures extending almost to the Susquehanna River at the western extremity. The geologic structure of the Southern Field is more complicated than that of the other fields. The dips of the synclinals and anticlinals are much steeper than elsewhere, and mining conditions are difficult. The largest tonnage of anthracite reserve lies in this Field.

3. Economy

Approximately 95 per cent of the Nations' true anthracite lies in Pennsylvania in the watersheds of the Susquehanna and Delaware Rivers. This, the "hard coal" of commerce, has found its greatest use as a domestic and industrial fuel. Since 1808 the anthracite industry has shipped over five billion tons of clean coal. Peak production was slightly more than 100 million tons (2). Production has decreased gradually to a low of about 16.5 million tons in 1964.

Production during the period 1962-64 was only 75 per cent of that during the 1946-48 period. Strip and underground mining production declined by 33 per cent and 83 per cent, respectively.

Projected estimates of anthracite production for the area are as follows:

Projected Anthracite Production (Thousand Short Tons) (7)

	1970	1985	2020
Susquehanna Basin	5,900	3,200	2,500
Delaware Basin	5,300	4,200	9,500

Anthracite coal reserves within the Susquehanna River Basin have been estimated at 8.2 billion short tons. Recoverable reserves are estimated at 1.6 billion short tons. (5)

4. Sub-Basin Description

A detailed discussion of the mine drainage sources in the Anthracite Area, their effect on stream quality, and possible abatement methods follow:

a. Lackawanna River

(1) Mine Drainage Sources and Their Effect on Stream Quality

Changes in mining activity and mine drainage discharge points have greatly altered the quality of the Lackawanna River within the past 10 years. Prior to 1960, extensive mining with associated mine drainage discharges severely degraded stream quality. Declines in demand for anthracite coal, the cost of pumping high volumes of water encountered, and other circumstances gradually forced the abandonment of most of the deep mines in the watershed.

Cessation of mine water pumping resulted in a very significant increase in stream alkalinity although some mine drainage influence on stream quality persists.

In January 1961, the mine water pools which had been developing in the abandoned underground workings broke through the surface in the form of a gravity discharge to the Lackawanna River at Duryea, approximately two miles from its mouth. The largest discharge of mine drainage in the Anthracite Field is a combination of the "Duryea Gravity Discharge" and the discharge from a borehole, which was subsequently drilled one mile upstream at Old Forge in order to stabilize the level of the underground pools. The combined discharges contribute an average flow of about 58 mgd, an acid load of approximately 132,000 lbs/day net acidity, and an iron load of approximately 62,000 lbs/day.

Although most of the mine water developed in the Lackawanna River watershed discharges to the river through the Duryea and Old Forge discharge points, as illustrated in Figure 6, water quality in the river is also influenced by other mine drainage discharges.

The initial effect of mine drainage on stream quality is evident immediately above Carbondale, Pennsylvania, downstream from Elk Creek. This stream receives mine drainage from two deep mines. At Carbondale, further water quality impairment occurs as a result of discharges from two deep mines. Based on an acidity-alkalinity balance, this reach of the Lackawanna River receives a net acid loading of at least 1,000 lbs/day from the combined flows described above.

Between Carbondale and Old Forge, the river receives mine drainage contributed primarily by the Jermyn Water Tunnel, which contributes approximately 5,500 lbs/day net acidity.

Below the entry of the Jermyn discharge and the confluence with the Susquehanna River, the Lackawanna River receives the Duryea and Old Forge discharges. These discharges overcame the stream's residual alkalinity and were primarily responsible for the acid loading of 47,000 lbs/day net acidity discharged to the Susquehanna River during the sampling period. The Lackawanna River discharge does not deplete the Susquehanna River's alkalinity reserve; however, iron loadings originating in the Duryea and Old Forge discharges are responsible for substantial degradation of the quality of the Susquehanna River.

Variation of mine drainage indicators throughout the length of the river is illustrated in Figure 7-A. At its mouth the pH is generally between 4 and 6. The acidity concentration is about 150 mg/l and iron and manganese concentrations are normally in the 50 mg/l and 10 mg/l range, respectively.

(2) Abatement and Control Measures

Because of the vast extent of the underground mine workings and the large area disturbed by surface mining in the Sub-Basin, it is doubtful that reclamation work alone will constitute a completely effective pollution abatement program. This work, although needed to reduce the amount of surface water which is diverted to the underground mine workings, will not completely abate mine drainage pollution in the Lackawanna River watershed. Treatment conveyance, or some other abatement method will also be needed.

A consulting engineer under contract with the Pennsylvania Sanitary Water Board has completed a preliminary study of methods and the associated costs of lowering the underground mine water pools below the level of the Duryea and Old Forge discharges and constructing lime neutralization facilities to treat the new combined discharge. The cost of facilities to collect and treat the present average flow is estimated to be $4.3 million. Total annual cost of the facility is estimated to be $760,000.

b. Susquehanna River-Lackawanna River to Nescopeck Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

The quality of the Susquehanna River is impaired in this reach by mine drainage contributed by the Lackawanna River and by discharges originating in the Wyoming Valley portion of the Northern Anthracite Field. Tributary streams contributing most of the mine drainage originating in the Wyoming Valley include: Mill Creek, Solomons Creek, Warrior Run, Nanticoke Creek, and Newport Creek. The streams act as conveyances for discharges from large mine-pumping stations. The qualities of the tributaries approximate the qualities of contributing discharges.

The discharges originate in active deep mines and in abandoned deep mines in which the level of the pool is maintained constant by pumping to prevent the water from entering areas where mining is actively accomplished.

All of the pumping operations which contribute a significant amount of acid to the Susquehanna River are operated by the Blue Coal Company. The company operates a total of 27 pumps at 17 locations. Pumps which stabilize the pool level in abandoned mines were purchased and installed with public funds provided by equal allocations by the State and Federal Governments to a $8.5 million fund, the Joint Federal-State Anthracite Mine Water Control Program, which was established in 1955. Of the $7 million of the appropriations which have already been spent, $5 million was spent for 26 deep-well pumps operated, at some time, by the Glen Alden Coal Company, predecessor of the Blue Coal Company.

The total flow of pumped discharges averages 62 mgd, the acid loading averages 361,000 lbs/day net acidity and the iron loading averages 134,000 lbs/day.

Under the direction of the Pennsylvania Sanitary Water Board, the company regulates its discharges in accordance with streamflow, pumping only as necessary to prevent flooding of the active mines during low streamflow periods. Calculations based on pumping records and discharge and stream quality records indicate the following contributions from major sources during the period of sampling in the area -- August 1965:

(a) Mill Creek - 85,000 lbs/day net acidity from the Delaware pumps.

(b) Solomons Creek - 26,700 lbs/day net acidity from Huber (14,700 lbs/day) and the treated South Wilkes-Barre #5 discharge (12,000 lbs/day). The latter discharge is permitted only with treatment during low flow periods and was active only during the period August 19-31.

(c) Warrior Run - 3,600 lbs/day net acidity originating in discharges from Sugar Notch #3 West (840 lbs/day) and Sugar Notch Shaft (2,830 lbs/day).

(d) Nanticoke Creek - 24,000 lbs/day from the Askam pumped discharge. The Loomis outfall, permitted with treatment during the low flow period, was operated only 53 hours during the month and is not considered here.

(e) Newport Creek - 18,000 lbs/day net acidity from the Wanamie mining complex.

The total contribution of 147,000 lbs/day net acidity was, during the sampling period, about half of the average contribution from these sources as indicated by pumping records and miscellaneous water quality data available.

Although the river received sizable acid contributions from the pumped discharges during the survey period, as shown in Figure 7, its alkaline reserve was not seriously threatened. Other mine drainage indicators, particularly manganese and sulfates, were, however, present in relatively high concentrations.

Samples collected in August 1966 at Mile 196 upstream from the Lackawanna River and at Mile 179 downstream from all significant Northern Anthracite Field mine drainage sources indicate a significant reduction in alkalinity and increases in other mine drainage indicators through the reach. Alkalinity dropped from about 84 mg/l to 38 mg/l. Iron, manganese, and sulfates increased from 0.1, 0.09, and 30 mg/l to about 0.3, 1.5, and 190 mg/l, respectively. During the sampling period iron concentrations in this reach were abnormally low. Other data available indicates that the change in concentrations of iron and other mine drainage indicators through the reach is considerably more dramatic under other flow conditions.

The last regularly sampled discharge in this reach is a gravity discharge from an isolated mine water pool at

Mocanaqua. The discharge contributed approximately 6,000 lbs/day net acidity and had no observable effect on the alkaline reserve of the Susquehanna River.

Downstream from Nescopeck Creek, stream quality rapidly improves. Downstream tributaries draining the Anthracite Area, while contributing mine drainage indicators, do not significantly affect stream quality. Biological surveys determined significant degradation of aquatic life in the reach from the Lackawanna River to Nescopeck Creek and slight effect further downstream. Periodic degradation of stream quality downstream from Nescopeck Creek has been observed during periods of high stream flow following extended low flow periods. Iron salts which precipitate during low flow periods to form sludge deposits in the river upstream from Berwick are scoured out by increased stream velocities and are evident downstream to the confluence with the West Branch Susquehanna River.

(2) Abatement and Control Measures

The Blue Coal Company and its predecessor, the Glen Alden Coal Company, have, in accordance with Sanitary Water Board requirements, restricted pumpage during low stream flow periods and in some cases provided lime neutralization of key discharges in an effort to minimize the effect of its discharge on stream quality. Although this action has preserved the alkaline reserve of the Susquehanna River, additional action is needed to abate water quality degradation caused by other mine drainage indicators. Treatment of at least a portion of the present average discharge will, no doubt, be required as a part of any effective pollution abatement program in the Area.

A preliminary study conducted in 1962 by a consulting firm retained by the Glen Alden Coal Company estimated that lime neutralization type mine drainage treatment facilities to treat the Company's pump discharges, which were then slightly larger than those at present, would cost about $18.9 million. Average annual costs were estimated to be about $4 million.

The Mocanaqua gravity discharge is presently under study preparatory to carrying out abatement work as a part of a joint U. S. Bureau of Mines - FWPCA Mine Drainage Demonstration Project. Work on this discharge, while not of major significance to stream quality, may point to ways of abating polluting discharges in other portions of the Anthracite Area.

c. Nescopeck Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

The results of a sampling program conducted during August and September 1965 indicate that the quality of the upper reaches of Nescopeck Creek above its confluence with

Little Nescopeck Creek is not significantly degraded by mine drainage. In fact, this 10-mile reach is classified as a trout stream by the Pennsylvania Fish Commission. Below the confluence, however, stream quality is degraded by the contribution of mine drainage from Little Nescopeck Creek and Black Creek.

Initial water quality degradation in Nescopeck Creek is caused by mine drainage contributed by Little Nescopeck Creek. As Figure 8 illustrates, the contribution of approximately 7,000 lbs/day net acidity by Little Nescopeck Creek overcomes Nescopeck Creek's natural alkaline reserve and renders it an acid stream.

The prime source of pollution of Little Nescopeck Creek is the Jeddo Tunnel, which serves as a gravity discharge point for a large area of abandoned deep mine workings in Black Creek Coal Basin in the Western Middle Field.

The tunnel discharged an average of about 20 mgd with an acid loading of 98,000 lbs/day net acidity during the sampling period.

The quality of Nescopeck Creek improves slightly from its confluence with Little Nescopeck Creek to its mouth. Although Black Creek contributes sizable loadings of mine drainage indicators (the acid contribution was 14,000 lbs/day), concentrations of mine drainage indicators are less than those in

Nescopeck Creek. The mixture of the two streams thus slightly improves the quality of Nescopeck Creek.

During the survey period, the mean acidity was 240 mg/l and the mean manganese concentration (8 mg/l) exceeded the total iron concentration (6.5 mg/l) in Nescopeck Creek immediately downstream from the confluence with Little Nescopeck Creek. Stream quality gradually improved in the 18 miles to the mouth. However, as shown in Figure 8, stream quality was still poor at the mouth.

Black Creek receives mine drainage discharges from the Gowan and Derringer Drainage Tunnels, which are believed to be the major mine drainage contributors in the watershed.

In addition to mine drainage pollution, Little Nescopeck Creek and Black Creek receive contributions of coal silt from coal-processing operations and surface runoff from piles of coal fines.

(2) Abatement and Control Measures

Since most of the mine drainage contributed to Nescopeck Creek can be attributed to three drainage tunnels, treatment as a primary abatement method may be feasible. Conveyance or diversion of the mine drainage to an adjacent stream basin or the Susquehanna River may be a feasible interim step. Since the drainage tunnels were drilled for the express purpose of collecting and providing gravity drainage for the mine water from a large area in the coal field, mine flooding and surface restoration as primary abatement methods would probably be quite costly and have limited prospects of complete success.

d. Catawissa Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

As a result of mine drainage contributions, Catawissa Creek is an acid stream throughout most of its length.

Approximately 38 miles from its mouth, the stream, which at that point is normally alkaline although bearing evidence of mine drainage contributions, is diverted underground in an abandoned surface mining complex which has completely disrupted surface drainage patterns. The stream then apparently flows through abandoned deep mine workings for a distance of approximately 4,000 feet, emerging as the Green Mountain Water Level Tunnel discharge. The stream, bearing an acid load of about 150 lbs/day net acidity during the study period, is further degraded about three miles downstream by the contribution of a total of about 24,000 lbs/day net acidity from two drainage tunnels, Audenreid and Green Mountain. The stream, as shown in Figure 9, never recovers from this heavy acid loading.

As Figure 9-A illustrates, iron, manganese, and net alkalinity concentrations were essentially equivalent to those measured in Nescopeck Creek. Sulfate concentrations were, however, about twice as great in Catawissa Creek as in Nescopeck Creek.

Tomhicken Creek, with its contribution of 1,700 lbs/day net acidity during the survey period, constitutes the only other significant contributor of acid and other mine drainage indicators. Its contribution does not, however, significantly degrade the quality of Catawissa Creek, since indicator concentrations are somewhat lower than those in the receiving stream. Most of the acid contributed by Tomhicken Creek originates from the Cox #3 drainage tunnel, which contributed about 1,200 lbs/day net acidity during the survey.

Although all of the known mine drainage discharges enter Catawissa Creek in the upper one-third of its length, the weak natural alkalinity and relatively small flow of downstream tributaries are not adequate to neutralize the heavy acid loadings contributed in the headwaters. Catawissa Creek contributed approximately 18,500 lbs/day net acidity to the Susquehanna River during the sampling period. This loading was about 80 per cent of the largest single contribution, the Audenreid Drainage Tunnel.

Unlike many of the streams in the Anthracite Area, Catawissa Creek is not significantly influenced by coal silt.

This absence of coal silt probably stems from the fact that there are no active coal processing operations in the Sub-Basin.

(2) Abatement and Control Measures

A comprehensive mine drainage pollution abatement program in the Sub-Basin would involve restoration of surface drainage, reclamation, mine flooding, and probably treatment.

Abatement of polluting characteristics of the Audenreid discharge would provide an immediate benefit by restoring Catawissa Creek to an alkaline condition, although its quality would be somewhat degraded by other discharges.

A consulting engineer under contract with the Chesapeake Bay-Susquehanna River Basins Project is presently studying methods and associated costs of abating pollution from mine drainage originating in the coal basin drained by the Green Mountain Tunnel and Green Mountain Water Level Tunnel.

e. Shamokin Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

Shamokin Creek is an acid stream throughout 28 miles of its 35-mile length. The remaining seven miles, the extreme headwaters, although alkaline, were found to have high concentrations of mine drainage indicators, particularly iron and mangenese. As shown in Figure 10, downstream from

Mile 29 the stream is rendered acid by mine drainage contributed by the North Branch Shamokin Creek and the Excelsior Drainage Tunnel. Although the acidity decreased fairly uniformly from about 200 mg/l at this point to about 100 mg/l at the mouth, the acid loading increased from about 9,000 lbs/day net acidity to about 35,000 lbs/day net acidity in the next 10 miles, then remained constant the remaining 18 miles to the mouth.

As shown in Figure 10-A, the total iron concentration reached a peak of 147 mg/l at Mile 23 then declined to less than 20 mg/l at its mouth. Mean manganese concentrations ranged from 6 mg/l to 3 mg/l along the length of the stream. Sulfate concentrations ranged from 470 mg/l at Mile 22 to 430 mg/l at the mouth.

In the Shamokin Creek watershed, all mine drainage discharges enter in the headwaters area, which is typical of the Anthracite Fields. Seven major discharges were located in the upstream third of Shamokin Creek drainage. All the discharges originated in underground mines, although they were undoubtedly influenced by surface water diverted underground in areas disturbed by surface mining. At the time of sampling, the seven major discharges contributed a flow of 13.1 mgd and 38,000 lbs/day net acidity.

Additional study of this watershed is needed to confirm the origin of the major acid loads; however, it is believed that most of the acid originates in abandoned mines and is conveyed to the stream by drainage tunnels.

In addition to constituents attributable to mine drainage, the stream is heavily laden with coal silt, much of which apparently originates at coal cleaning and processing operations in the Sub-Basin.

(2) Abatement and Control Measures

A comprehensive mine drainage pollution abatement and control program in the Sub-Basin would involve extensive surface mine reclamation, mine flooding, reclamation of spoil banks, and, undoubtedly, treatment. Since much of the drainage is collected by drainage tunnels and discharge points are not numerous or widely scattered, treatment may prove feasible. As a first step, treatment or diversion of the Excelsior discharge and surface restoration might be a feasible method of reclaiming a 12-mile reach upstream from the Borough of Shamokin, where the remaining major discharges are clustered.

f. Mahanoy Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

Mahanoy Creek, although contributing a loading of approximately 1,000 lbs/day net alkalinity to the Susquehanna River, is one of the most severely degraded streams draining the Anthracite Area. A study carried out in July, August, and

September 1965 determined the source of stream quality degradation to be alkaline discharges which contained high concentrations of iron, manganese, and other mine drainage indicators. Severely degraded stream quality was observed throughout the entire 52-mile length of Mahanoy Creek.

Major contributions of mine drainage reach Mahanoy Creek through the following tributaries: North Branch Mahanoy Creek, Waste House Run, Shenandoah Creek, Big Mine Run, Big Run Creek, and Zerbe Run. In addition, five large deep mine discharges enter Mahanoy Creek directly.

As shown in Figure 11 and 11-A, the stream's natural alkalinity is overcome in its upper reaches. This is primarily the result of an 800 lbs/day net acidity contribution from the East Barrier Gravity discharge, an intermittent pumped discharge from the Springdale Tunnel which was discharging 4,200 lbs/day net acidity on the one day during the survey when it was found to be discharging, and a 10,500 lbs/day net acidity contribution by Waste House Run which originates in predominately pumped discharges.

Alkaline contributions by the Girardville #1 and #2 Drainage Tunnels and Big Mine Run overcame the acid residual and increased the stream's alkaline reserve to a peak of approximately 15,000 lbs/day at a sampling station downstream from Big Mine Run. This reserve steadily decayed to a minimum of 1,000 lbs/day at the mouth. Reductions in the alkaline reserves occurred in response to contributions of acid and to the oxidation of acid precursors contributed in the large alkaline discharges. The largest acid contribution in the portion of the Basin downstream from Big Mine Run was Zerbe Run with its loading of 7,900 lbs/day net acidity. Zerbe Run received essentially all of its acid loading from the Trevorton Tunnel discharge which contributed 12,000 lbs/day net acidity.

As illustrated on Figure 11-A, concentrations of mine drainage indicators vary greatly along the length of the stream. Mean manganese concentrations range from 2.7 mg/l to 20 mg/l; mean total iron concentrations range from 3 mg/l to 110 mg/l. Sulfate concentrations range from 1,050 mg/l to 1,500 mg/l throughout most of the length of the stream.

Coal silt discolors the stream and practically chokes the channel in some reaches.

(2) Abatement and Control Measures

This Sub-Basin will be one of the most difficult in the Anthracite Area in which to develop an effective pollution abatement program because of the large area involved and the large number and variety of quality of discharges. Since a number of the major discharges originates in active mines, treatment will probably play a major role in any pollution abatement program. Mine drainage and conveyance facilities may be applicable in combining acid and alkaline discharges prior to their entering the stream.

Treatment facilities such as ion exchange or distillation would appear to be the most applicable in reducing the polluting characteristics of the alkaline discharges which have high concentrations of other mine drainage constituents.

The magnitude and complexity of the work necessary in the Sub-Basin suggest that it receive a low priority if only a limited abatement program is possible in the Anthracite Area.

g. Mahantango Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

Mahantango Creek is an acid stream throughout approximately 17 miles of its 32-mile length and contributes approximately 3,500 lbs/day net acidity to the Susquehanna River.

Essentially all of the mine drainage discharged in the Mahantango Creek Sub-Basin comes to the surface in the watershed of Rausch Creek, a small (10-square-mile drainage area) tributary to Pine Creek, which is in turn a tributary of Mahantango Creek.

Rausch Creek, with its acid loading of 5,000 lbs/day net acidity, exhausts the alkaline reserve of Pine Creek at their confluence and renders it an acid stream for the remaining 13 miles of its length. The quality of Pine Creek is slightly improved by water contributed by alkaline tributaries, the largest of which is Deep Creek. Although influenced by mine drainage originating in the Hans Yost Creek watershed, Deep Creek contributes an alkaline loading of about 70 lbs/day net alkalinity.

As shown in Figure 12, the residual acid loading of about 3,000 lbs/day net acidity which reaches Mahantango Creek easily overcomes its weak alkaline reserve and renders it an acid stream to its mouth. The portion of Mahantango Creek upstream from Pine Creek, although low in alkalinity, is of generally good quality. A biological reconnaissance in 1964 determined that this reach supported normal aquatic life.

Upstream from Pine Creek, Mahantango Creek is almost free of all mine drainage indicators and has, in fact, surprisingly low mineral content. For example, its mean sulfate concentration was 7 mg/l. Mean iron and manganese concentrations were 0.4 mg/l and 0, respectively. Downstream from Pine Creek stream quality was relatively constant. Iron and manganese concentrations were slightly less than 0.6 mg/l. Mean net acidity ranged between 35 and 45 mg/l (See Figure 12-A).

Mine drainage sources in the Mahantango Creek Sub-Basin, although clustered in a relatively small area of the

Rausch Creek watershed, are not, as is the case in some of the sub-basins already discussed, collected by drainage tunnels. Mine drainage is contributed to Rausch Creek through 22 known pumped discharges and 10 gravity discharges, the largest of which are the Markson and Valley View discharges. These two discharges were responsible for a total contribution of 1,600 lbs/day net acidity during the sampling period.

(2) Abatement and Control Measures

Because of the large number of discharges and the large percentage of active operations in the Sub-Basin, abatement of pollution in the immediate future would probably be accomplished most feasibly by treatment. A treatment plant to treat the entire Rausch Creek flow would have been called upon to treat approximately 5 mgd during July 1965, the period of sampling in the Sub-Basin. This, while admittedly a low-flow period, is an indication that the treatment plant required would not be unusually large. Because of the low acidity concentrations encountered and the general low mineralization of the waters of the Sub-Basin, treatment should be relatively inexpensive because alkaline reagent needs would be modest and volumes of sludge produced would be low, thereby minimizing the cost of sludge disposal.

In view of the great length of stream influenced by mine drainage originating in the Rausch Creek watershed, the relatively low expected cost of treatment, and the relative ease of collecting sources of mine drainage for treatment, this Sub-Basin should receive high priority in any limited mine drainage pollution abatement program.

h. Wiconisco Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

Wiconisco Creek is an alkaline stream throughout its length and it contributed approximately 6,000 lbs/day net alkalinity to the Susquehanna River during a survey of the Sub-Basin in 1965. Its quality is degraded by coal silt, untreated sewage, and mine drainage indicators for at least a portion of its length.

The major mine drainage sources located during the survey were the Porter and Keefer Drainage Tunnels and Bear Creek, which receives its mine drainage contribution from two drainage tunnels. All of the major discharges are located in the upper one-third of the stream's length. Figure 13 illustrates the effect on stream alkalinity reserves of the contribution of 6,000 lbs/day net alkalinity by Bear Creek, which overcomes the effect of 900 lbs/day net acidity contributed by the Porter and Keefer Tunnels.

Although iron, manganese, and sulfate concentrations in Wiconisco Creek are temporarily elevated by contributions from Bear Creek, about 25 miles of stream downstream from

Bear Creek are of relatively good chemical quality (See Figure 13-A). A summary of a biological survey of the stream conducted in 1964 reports essentially no aquatic life upstream from Bear Creek. Several species of clean water organisms were collected at the mouth, indicating at least partial recovery from the upstream pollution loadings.

Coal silt loadings in the stream were heavy. These apparently originated in coal washeries in the Sub-Basin.

(2) Abatement and Control Measures

Because of the relatively small number, low volume, and low strength of major discharges in this Sub-Basin, abatement work could probably be accomplished at relatively low cost. Lime neutralization and conveyance to combine acid and alkaline discharges would appear to be applicable. As in the Mahantango Creek watershed, low dissolved solids concentrations in the major mine drainage sources suggest that treatment could be accomplished with minimum utilization of costly sludge disposal facilities. Inundation of the numerous deep mines in the Sub-Basin would also probably prove beneficial. A parallel program aimed at abating polluting sewage and coal silt contributions to the streams should be undertaken.

i. Swatara Creek

(1) Mine Drainage Sources and Their Effect on Stream Quality

Mine drainage renders Swatara Creek acid from its headwaters to its confluence with Mill Run, a distance of approximately 24 miles. Streams found to be contributing significant amounts of mine drainage to Swatara Creek during a survey of the Sub-Basin in October and November 1965 were: Panther Creek, Good Spring Creek, and Lower Rausch Creek. As illustrated in Figure 14, Panther Creek, with its contribution of only 13 lbs/day net acidity, does not significantly affect the alkalinity reserve of Swatara Creek. It does, however, contribute other mine drainage indicators. Figure 14 illustrates how the alkalinity reserve of Swatara Creek was affected by the contribution of 2,000 lbs/day net acidity from Good Spring Creek. Most of the mine drainage in the Good Spring Creek watershed originates in the watershed of Middle Creek, a tributary which enters Good Spring Creek about one mile from its mouth.

Lower Rausch Creek contributed a net acid loading of 1,300 lbs/day, most of which originated in three drainage tunnel discharges.

As shown in Figure 14, the acid loading in Swatara Creek reached a peak of 3,600 lbs/day net acidity at Mile 58, immediately downstream from Lower Rausch Creek, and then declined in response to the influence of alkaline tributary streams.

As illustrated in Figure 14-A, stream quality in the headwaters reach fluctuates rather weakly in response to contributions by streams bearing mine drainage. Mean iron and manganese concentrations were about 3.5 mg/l. Sulfate concentrations were normally less than 250 mg/l. Downstream from Mile 60, concentrations of all mine drainage indicators declined.

Considerable mining is presently being accomplished in the Sub-Basin; however, most of the significant mine drainage discharges observed during the survey originated in abandoned mines. About 4,600 lbs/day net acidity loading on the stream during the survey could be attributed to four deep mine discharges and the discharge of Middle Creek.

(2) Abatement and Control Measures

A portion of the Middle Creek watershed is presently being studied by a consulting engineer under contract with the Chesapeake Bay-Susquehanna River Basins Project to determine alternate pollution abatement measures and associated costs.

The Pennsylvania Department of Mines and Mineral Industries is presently carrying out a reclamation program in the Middle Creek watershed. Work recently completed prevents a small tributary of Coal Run from entering the underground mine workings and subsequently emerging as an acid mine drainage discharge. Planned work will involve reclamation of other areas disturbed by surface mining. When completed, the project will probably substantially reduce the mine drainage contribution to Middle Creek.

Since acid loadings on Swatara Creek are relatively low, a minimum of reclamation work may at least restore the alkalinity of Swatara Creek. Complete abatement of mine drainage pollution will probably involve treatment of all active mine discharges and certain inactive discharges which are not amenable to abatement by other methods.

j. Schuylkill River

(1) Mine Drainage Sources and Their Effect on Stream Quality

The Schuylkill River, a tributary of the Delaware River, drains a large portion of the Southern Anthracite Field.

Tributaries discharging significant amounts of mine drainage to the Schuylkill River include Mill Creek, West Branch Schuylkill River, and the Little Schuylkill River.

The Schuylkill River is rendered acid at its headwaters, apparently by runoff from refuse piles. Numerous discharges from all source categories add to the acid load upstream from the confluence with Mill Creek. Eleven major discharges to this reach contributed 2,200 lbs/day net acidity on the day of sampling.

Mill Creek received drainage from four major discharges and contributed approximately 11,000 lbs/day net acidity on the day of sampling.

The next downstream source of acid is the West Branch Schuylkill River. The West Branch receives drainage from numerous mines of all source categories and contributed approximately 4,500 lbs/day net acidity on the day of sampling. Most of the acid contributed by the West Branch may be attributed to one drainage tunnel which had an acid contribution of 6,900 lbs/day on the day of sampling.

The Little Schuylkill River is rendered acid at its source by several drainage tunnel discharges and receives additional acid from Wabash Creek (2,000 lbs/day) and Panther Creek (6,000 lbs/day). Although no samples were collected downstream from the mine drainage sources, it is believed that the quality of the Little Schuylkill River is degraded by mine drainage throughout its length. Nine major discharges contributing about 6,000 lbs/day net acidity were located in this watershed. Drainage originated in both active and inactive mines.

Acid contributed in the headwaters coupled with the acid contributed by Little Schuylkill River render the Schuylkill River acid downstream to Reading.

Mine drainage discharges and the receiving streams in this Sub-Basin are generally low in iron and manganese concentrations. Net acidity and sulfate concentrations are relatively high.

The quality of the Schuylkill River immediately downstream from the West Branch Schuylkill River is representative of the quality of most of its upstream tributaries. On the day of sampling the net acidity was 78 mg/l. Sulfate, iron, and manganese concentrations were 590 mg/l, 2.5 mg/l, and 7.8 mg/l, respectively.

(2) Abatement and Control Measures

Because of the wide variety of sources and large geographic areas involved, abatement of mine drainage pollution by reclamation alone would probably not be feasible in this Sub-Basin. Since mine drainage discharges in the Sub-Basin have relatively low iron concentrations, treatment of major discharges or in-stream treatment might be accomplished at relatively low cost since the need for costly sludge handling facilities would be minimal.

k. Lehigh River

(1) Mine Drainage Sources and Their Effect on Stream Quality

Mine drainage contributed to the Lehigh River originates in the eastern edge of the Eastern Middle and Southern Anthracite Fields.

Streams contributing significant amounts of mine drainage to the Lehigh River include: Sandy Run, Buck Mountain Creek, Black Creek, and Nesquehoning Creek. Essentially all the mine drainage in this Sub-Basin originates in abandoned mines. Upstream from Sandy Run, the Lehigh River is almost neutral with a very low mineral content. Sandy Run with its acid load of 6,000 lbs/day net acidity on the day of sampling overcomes the weak natural alkalinity reserve and renders the Lehigh River acid. About 80 per cent of the acid loading contributed by Sandy Run on the day of sampling originated in the Owl Hole Drainage Tunnel discharge. Both Sandy Run and Pond Creek, its major tributary, are rendered acid from source to mouth by drainage from six major discharges, three of which are drainage tunnels.

Buck Mountain Creek contributed about 1,900 lbs/day net acidity to the Lehigh River on the day of sampling. Essentially all of the acid originated in the discharges from two drainage tunnels, Buck Mountain #1 and Buck Mountain #2. The tunnels discharge to the extreme headwaters of Buck Mountain Creek and render it acid throughout its length.

Black Creek contributed to the Lehigh River approximately 5,000 lbs/day net acidity, all of which originated in one discharge, the Beaver Meadow (Quakake) Drainage Tunnel. The discharge constitutes most of the flow of Quakake Creek, a tributary of Black Creek. Both streams are rendered acid by the discharge. Because of its large flow, Nesquehoning Creek, although only weakly acid at its mouth (13 mg/l on the day of sampling) contributed a sizable net acidity of 1,200 lbs/day to the Lehigh River. The Creek is acid throughout its length and receives most of its acid load from two drainage tunnels.

Although no samples were collected downstream from the acid tributaries on the day of sampling, other available data indicate that the Lehigh River is severely degraded by the mine drainage downstream to Northampton.

The quality of mine drainage discharges in this Sub-Basin is similar to that in the Schuylkill River watershed. The iron and manganese concentrations are relatively low, while acidity and sulfate concentrations are high.

(2) Abatement and Control Measures

It is doubtful that reclamation measures alone will be adequate to restore the quality of the Lehigh River and its tributaries to an acceptable level. Treatment of all nine major discharges to the Sub-Basin would involve treatment of a total of only about 4 mgd under low flow conditions. In view of the benefits to be derived from abating pollution in 39 miles of the Lehigh River, a major river, treatment would appear to be feasible. Because of the low iron concentration in most of the discharges, sludge handling costs associated with lime-neutralization-type treatment plants should be moderate. In-stream neutralization might also prove feasible.

E. North Branch Potomac River

1. Introduction

The North Branch of the Potomac River rises in Tucker County, West Virginia, and flows alternately northeast and southeast in a zigzag pattern for about 98 miles until it meets the South Branch to form the Potomac River (See Figure 1-E).

The North Branch forms the boundary between Maryland and West Virginia downstream from Kempton, Maryland. The North Branch is bounded on the Maryland side by Garrett and Allegany Counties and on the West Virginia side by Grant, Mineral, and Hampshire Counties.

The coal-bearing area of the North Branch Basin lies in a continuous trough-shaped valley about 80 miles long, oriented in a northeast-southwest direction. The North Branch flows northeast through the center of the Basin for almost two-thirds of its length, then bends southeast at Westernport, Maryland, and leaves the coal region. The northeast part of the valley is drained by Georges Creek, which flows southwest through the center of the valley to join the North Branch at Westernport. The coal-bearing region southwest of Westernport is known as the Upper Potomac Coal Fields. The coal region drained by Georges Creek, Savage River, and two small tributaries of Wills Creek is known as the Georges Creek Coal Field. Coal is mined from the Pittsburgh, Tyson, Bakerstown, Waynesburg, Freeport and Kittanning coal seams.

2. Economy

Cumberland, Maryland, is the largest population center in the North Branch Basin and is the railroad and industrial center of the area. Cumberland has been a transportation center since the early 1800's when the National Road (now U. S. 40) was built. During the 1820's the Baltimore and Ohio Railroad and the Chesapeake and Ohio Canal reached Cumberland. Today the area is also served by the Western Maryland Railroad and the Pennsylvania Railroad. In addition to the railroad, three large industrial plants, with employment ranging from 1,100 to 3,100, are located in the Cumberland area.

The remainder of the Basin is sparcely populated. Principal towns are Frostburg, Barton, Lonaconing, Oakland, and Luke-Westernport in Maryland and Piedmont and Keyser in West Virginia. The West Virginia Pulp and Paper Company mill located in the tri-town area of Luke-Westernport-Piedmont employs 2,400 persons and is the largest "fine paper" mill in the world.

Coal has been mined in the North Branch Basin for about 150 years. A mine was operating before 1816 at Eckhart, Maryland, in the Georges Creek Coal Field. Good transportation facilities stimulated early development of

North Branch coal fields, particularly the Georges Creek Field.

Maryland's peak production of coal occurred in 1907, earlier than any other major coal-producing state. Coal production in the North Branch Basin for the 1961-1965 period was:

1961	1.0 million tons
1962	1.0 million tons
1963	1.3 million tons
1964	2.2 million tons
1965	3.3 million tons

The 1965 North Branch production amounted to 0.65 per cent of national production. About 2.2 million tons were mined in West Virginia (Upper Potomac Field) and 1.1 million tons in Maryland. Of the 1965 Maryland production, 624,000 tons were mined from the Upper Potomac Field. The Upper Potomac Field accounted for 85 per cent of the 1965 North Branch Basin coal production, and the West Virginia part of the Upper Potomac Field made up the bulk of the recent increases. In 1961 and 1962, Maryland accounted for about 75 per cent of the coal produced in the North Branch Basin; in 1965 Maryland accounted for only 33 per cent. While production for the entire North Branch Basin increased 330 per cent from 1961 to 1965, Maryland production increased only 60 per cent.

These increases are probably a result of the general U. S. economic upturn during these years, and are not indications of the long-term trend. However, they are significant in terms of present water quality.

Output per man increased three times as fast in Maryland during 1961-1965 as in the U. S. and the adjacent states; and in 1965 the output per man was much greater in the Maryland Upper Potomac Field than in the Georges Creek Field. The increased output was a result of new explorations and investment in new equipment and was also experienced in the West Virginia Upper Potomac Field.

Because of the increased output per man, mining employment in the North Branch Basin did not increase in proportion to production during 1961-1965. Employment for these years was:

1961	617
1962	567
1963	631
1964	784
1965	851

Of the 1965 employment, 373 were employed in Maryland and 478 in West Virginia. The figures include not only miners but all mine-associated employees.

The average value of Maryland coal in 1965 was $3.63 per ton f.o.b. mine, below the average U. S. price of $4.44

and the Pennsylvania (including anthracite) and West Virginia values of $5.07 and $4.87, respectively. Coal values have been stable since 1950. The average U. S. value f.o.b. mine fluctuated within a range of 69¢ per ton from 1950 to 1965. West Virginia Upper Potomac Field values were probably comparable. This makes the 1965 North Branch Basin 1965 production worth about $12 million, or 0.53 per cent of the value of all U. S. coal mined in 1965.

The West Virginia Upper Potomac 1965 production would have been worth $8 million, about 1 per cent of the total value of the West Virginia coal production. The Maryland 1965 production of $4 million was about three ten-thousandths of 1 per cent of the gross Maryland state product, and about 5 per cent of the total value of the mineral industry in Maryland.

3. Sub-Basin Description

During a sampling program conducted by the Chesapeake Bay-Susquehanna River Basins Project personnel in August and October 1966 and April 1967, the North Branch of the Potomac River was acid as a result of coal mine drainage from its source to Luke, Maryland. Until recently, spent process lime discharged by the West Virginia Pulp and Paper Company's Luke mill neutralized the acid contributed upstream; but the lime is no longer discharged and acid conditions will extend further downstream in the future.

Sampling by the Maryland Department of Water Resources (MDWR) in April, July, and November 1966 and a period of continuous monitoring by MDWR in April 1967 revealed similar conditions. This report is based partly on the MDWR data.

The data are the result of year-round sampling programs rather than low-flow surveys. They do, however, represent water quality at below average and relatively uniform flow conditions. In the few cases where samples were taken at high-flow conditions; the data were not used in computations. The highest sampling-time flows used in computations ranged from 25 to 50 per cent of the mean flows of record at gaging stations in the area, except for one sampling-time flow at Steyer, which exceeded the mean flow of record by 20 per cent.

The acid load at high flows was several times the load computed at below average flow conditions, although the high flow acid concentrations were always less than the low flow concentrations. There are acid slugs at high-flow conditions, probably as a result of a washout of acid accumulated in surface and sub-surface impoundments.

From its source to the area of Westernport, Maryland, where it leaves the coal region, the North Branch receives acid mine drainage from at least eleven tributaries (See Figure 1-E). Of these tributaries, Elk Run, Laurel Run, and Abram Creek contributed 65 per cent of the total measured net acidity load in the North Branch Basin.

Eighty-one per cent of the total net acidity measured in the stream originated in the Upper Potomac Coal Field, 2 per cent in the Georges Creek Field, and 17 per cent was unaccounted. Fifty-seven per cent of the total measured net acidity originated in the headwaters above the USGS gage at Steyer, Maryland. West Virginia sources contributed 63 per cent of the total measured acid load in the North Branch Basin. Maryland tributaries added 20 per cent.

In 1966, a total of 130 miles of stream in the North Branch Basin was continuously polluted by mine drainage, and an additional 30 to 40 miles were mildly or intermittently affected. Most of these streams carried a net acid load. There are few sources of natural alkalinity in the region. Shales and sandstones containing coals and fire clays dominate the geology. There is only one limestone stratum in the North Branch Basin, and that lies in the Georges Creek watershed.

Biological sampling throughout the North Branch Basin revealed, in general, only sparse populations of acid-tolerant benthic organisms. In several cases, no benthic life could be found. These conditions are attributed to mine drainage pollution. Except in Georges Creek watershed, sewage pollution is not a significant problem, and there are no industrial discharges upstream from Luke.

4. Mine Drainage Sources and Their Effect on Stream Quality

A detailed discussion of the mine drainage sources in the North Branch Basin and their effect on stream quality follows:

a. North Branch Headwaters to Steyer, Maryland

The North Branch was sampled at Kempton, Maryland, approximately two miles downstream from its source. As shown in Figure 15, at Kempton the North Branch discharged 400 lbs/day net acidity, less than 1 per cent of the net acidity contributed in the Sub-Basin. Fourteen miles downstream from Kempton, at Steyer, Maryland, the net acidity load had increased to 52,000 lbs/day. The acidity measured at Steyer was 82 per cent of the total net acidity measured in the North Branch. The three tributaries discussed below discharged 36,000 lbs/day to the North Branch in this reach.

(1) Elk Run

Elk Run, a minor tributary in terms of drainage area, contributes more net acidity to the North Branch than any other tributary. At its confluence with the North Branch, Elk Run had a pH of 2.8, a mean net acidity concentration of 1,900 mg/l, a mean sulfate concentration of 11,000 mg/l and a mean total iron concentration of 3,500 mg/l. The measured flows ranged between 1.7 and 3.3 cfs, but the enormous acid concentration resulted in a mean contribution of 24,000 lbs/day net acidity to the North Branch. This load represents

38 per cent of the total measured net acidity in the North Branch. Elk Run's streambed was colored a bright orange, a purplish brick-red, and green (algae) and was covered with a crusted sediment more than a foot thick in many places. The Elk Run sampling station lies a few hundred yards downstream from a coalyard and mines operated by the Alpine Coal Company.

Three water samples collected at the same site by the West Virginia Division of Water Resources indicate that acid concentrations were roughly an order of magnitude lower than present concentrations as late as May 1966. Elk Run' acid load is due principally to recent mining operations.

(2) Laurel Run

Laurel Run discharged 8,900 lbs/day net acidity to the North Branch, 14 per cent of the total measured net acid load. Although there are strip mines in the watershed, most of the mine drainage originates in an abandoned deep mine near Kempton. Much of the mine is in West Virginia.

(3) Buffalo Creek

Buffalo Creek discharged 2,900 lbs/day net acidity to the North Branch, 5 per cent of the total measured net acid load in the North Branch Basin. Samples were taken a few hundred feet above the confluence with the North Branch at Bayard, West Virginia. The North Branch Coal Company yard is located upstream. Buffalo Creek also receives untreated sewage from Bayard. Except for Georges Creek, this is the only case of sewage pollution in the waters studied.

b. North Branch - Steyer, Maryland, to Kitzmiller, Maryland

Thirteen miles downstream from Steyer, at Kitzmiller, Maryland, the acid load in the North Branch was 64,000 lbs/day net acidity, an increase of 12,000 lbs/day over the load at Steyer. The acid load at Kitzmiller equals the total net acidity measured in the North Branch. Below Kitzmiller the net acidity contributions are small and are balanced by natural contributions of net alkalinity. The three tributaries discharging net acidity to the North Branch in this reach are: Stony River (1,600 lbs/day), Wolfden Run (120 lbs/day), and Abram Creek (8,400 lbs/day).

(1) Stony River

The quality of Stony River is very mildly influenced by mine drainage near Mount Storm, West Virginia, about 5 miles above its confluence with the North Branch. At Mount Storm the river supports trout. The only known contribution of mine drainage to Stony River is from Laurel Run, a small intermittently polluted tributary several miles upstream. Stony River itself does not flow through coal-bearing areas.

(2) Abram Creek

The 8,400 lbs/day acidity contributed to the North Branch by Abram Creek is 13 per cent of the total measured net acidity in the North Branch Basin. The major part of the mine drainage in Abram Creek originates in the headwaters at Bismark, West Virginia. The net acidity load at this point was 3,800 lbs/day. Downstream, at Mt. Pisgah, West Virginia, Abram Creek carried 9,000 lbs/day net acidity, a load substantially equal to that discharged to the North Branch. Two tributaries, Glade Run and Emory Creek, discharged an estimated total of 2,000 lbs/day net acidity below Mt. Pisgah, but some neutralization occurs before the water reaches the North Branch.

c. North Branch - Kitzmiller, Maryland, to Beryl, West Virginia

At Beryl, West Virginia, fourteen miles downstream from Kitzmiller, Maryland, the North Branch carried 62,500 lbs/day net acidity, a decrease of 1,500 lbs/day from the acidity loading at Kitzmiller. Measured contributions of net acidity in the Kitzmiller-Beryl reach amounted to 4,200 lbs/day, indicating that neutralization occurs in this reach. The North Branch is grossly polluted at Kitzmiller. Measured pH values were less than 3.5 and benthic sampling revealed no organisms. The four tributaries discharging net acidity to the North Branch between Kitzmiller and Beryl are:

(1) Three Forks Run

Three Forks Run discharged 1,900 lbs/day net acidity to the North Branch, 3 per cent of the total measured net acidity load in the North Branch Basin. It is grossly polluted by runoff from mines and possibly from spoil piles in the watershed. In August 1966, a pH of 1.8 was measured in Three Forks Run.

(2) Deep Run

Deep Run discharged an insignificant net acidity load to the North Branch, less than 1 per cent of the total measured net acidity in the North Branch Basin. Benthic sampling indicated sparse populations of clean-water organisms. Deep Run is mildly polluted by mine drainage.

(3) Elklick Run

Elklick Run was sampled once, during April 1967, just above its confluence with the North Branch. The stream lies in Maryland about a mile downstream from Shaw, West Virginia. Elklick Run contributed 600 lbs/day net acidity to the North Branch, about 1 per cent of the total measured load in the watershed.

(4) Piney Swamp Run

Piney Swamp Run contributed 2,500 lbs/day net acidity to the North Branch, or 4 per cent of the total measured net acidity in the watershed. Samples were taken at Hampshire, West Virginia, a few hundred feet above the confluence with the North Branch. The Hampshire station lies at the foot of an active mining area operated by Mastelier Coal Company. Above these operations, the flow in Piney Swamp Run is only about 15 per cent of the flow at the mouth and stream quality is considerably better than at Hampshire.

d. North Branch - Beryl, West Virginia to Cumberland, Maryland

Until recently, spent process lime discharged from the West Virginia Pulp and Paper Company mill at Luke, one-half mile downstream from Beryl, neutralized the acid load in the North Branch. Since late 1966, due to in-plant changes, this spent lime has been reprocessed within the plant. As a result, the acidity that originates upstream from the mill is no longer completely neutralized. Other waste discharges by the West Virginia Pulp and Paper Company mill reduce the acidity considerably. These effects have become more significant since the lime discharge was stopped. As a result of many years of lime discharge, the riverbed, during the most recent survey, was covered by a lime-gypsum sludge with considerable neutralizing capacity. Floods in the spring of 1967 probably washed out much of the sludge, but data are not available to indicate whether the river has reached equilibrium with the bottom or the extent to which acid conditions have moved downstream. Studies are continuing to determine the effects of mine drainage below Luke. Savage River and Georges Creek, the two tributaries in the Luke-Piedmont-Westernport area, exert minor effects in comparison to the mill. Tributary and mill effects are discussed below in the order in which they occur:

. (1) Savage River

The Savage River enters the North Branch a few hundred feet below the Beryl sampling station. The quality of the Savage River is mildly degraded by mine drainage in a one-mile reach from its mouth to Aaron Run. In this reach, Savage River maintains about 5 mg/l net alkalinity. This results in a discharge of 1,600 lbs/day net alkalinity, which is not adequate to appreciably reduce the net acidity load in the North Branch although some reduction in acid concentration occur by dilution. The Savage River is regulated to maintain a minimum flow of 93 cfs in the North Branch at Luke. Aaron Run, the only contributor of mine drainage to Savage River, is badly polluted. Upstream from Aaron Run, the water in Savage River is of excellent quality.

(2) West Virginia Pulp and Paper Company

The West Virginia Company withdraws more than 20 mgd of process water from the North Branch at Luke. This reduces the acid load by about 16,000 lbs/day or about 25 per cent. Waste is returned downstream at Westernport, except for boiler house, evaporator, and flyash discharges at Luke. These discharges have some neutralizing effect, but will be discontinued soon.

During April 1967, the Maryland Department of Water Resources monitored the pH of the North Branch below the West Virginia Pulp and Paper Company mill. The pH alternated between 3.5 and 4.5, depending presumably on intermittent discharges of alkaline waste. After the waste discharges are stopped, the pH will probably not rise above 4.0.

(3) Georges Creek

Georges Creek, which enters the North Branch at Westernport, Maryland, contributes 1,100 lbs/day net acidity, or 2 per cent of the total measured net acidity in the North Branch Basin. Most of the acidity in Georges Creek enters directly from deep mines which line the sides of the valley. Georges Creek is badly polluted by a combination of mine drainage and sewage.

(4) Upper Potomac River Commission Waste Treatment Facility

This waste treatment plant is located on the downstream side of Westernport, Maryland, 4½ miles below Beryl. About 95 per cent of the plant's load consists of process wastes from the West Virginia Pulp and Paper Company Luke mill. The UPRC plant discharges an average of 20 mgd, which contributes a load of 17,000 lbs/day net alkalinity to the North Branch. This is equivalent to 27 per cent of the total measured net acidity in the North Branch Basin. Three miles downstream from the UPRC plant, at Keyser, West Virginia, pH values between 6 and 7 were observed in the North Branch early in 1967.

(5) Wills Creek

Wills Creek, which enters the North Branch in downtown Cumberland, Maryland, does not contribute acidity to the North Branch, although mine drainage residual effects (high hardness and sulfate concentrations) are apparent in chemical data. Braddock Run and Jennings Run, tributaries which enter Wills Creek from the Georges Creek Coal Field to the west, are degraded by mine drainage. Braddock Run receives the discharge from the Hoffman Tunnel, a drainage tunnel bored in the early 1900's to drain deep mines in Georges Creek Basin.

At Cumberland, Maryland, high hardness and sulfate concentrations are apparent in North Branch chemical data, but acid conditions have not been observed.

5. Abatement and Control Measures

The North Branch Potomac River mine drainage sampling program was a stream sampling program designed to isolate tributary basins which contribute large amounts of acid to the North Branch. No program was undertaken to sample mine effluents. Because individual contributors are not yet known, an estimate of abatement costs is not possible.

The problem watersheds of Elk Run, Laurel Run, and Abram Creek contribute only 65 per cent of the total measured net acidity load. Completely eliminating these acid loads probably would not raise the pH of the North Branch above 6.0.

The largest contributions of acid to the North Branch Sub-Basin come from areas in which there are active mines. The proportion from active mines is believed to be significant.

Field work will be continued by the Project and State agencies to locate and characterize mine drainage discharges.

XI. ABATEMENT COSTS

The major sources of mine drainage pollution in most of the Study Area have been located as the result of studies conducted by the Chesapeake Bay-Susquehanna River Basins Project. Although sources of mine drainage pollution have been pinpointed and their flow and quality determined under one flow condition, data are not available to permit precise estimation of the cost of abating pollution under all flow conditions in each sub-basin influenced by mine drainage.

As previously noted, the least expensive method of abating mine drainage pollution in a given sub-basin might involve any combination of the many abatement measures available. Determination of the most appropriate combination of abatement measures and their associated costs would involve detailed engineering studies beyond the scope of Project activities.

To obtain an estimate of the order of magnitude of the cost of mine drainage pollution abatement in the Study Area, two separate approaches were taken: (1) Estimation of the cost of surface reclamation in areas disturbed by mining and (2) Estimation of the cost of lime neutralization treatment of major acid contributions located during periods of low flow. Although the first approach would theoretically abate pollution, a realistic appraisal indicates a conservative estimate of the cost of mine drainage abatement would be the sum of the two approaches. This conclusion is based on the assumption that mine drainage discharges located to date during the low-flow periods under which field activities are carried out represent the maximum annual residual mine drainage loading in each subbasin after all feasible land reclamation measures are applied.

The cost of reclamation of land disturbed by surface mining is estimated based upon average reclamation costs of $500/acre for the Bituminous Area and $2,500/acre for the Anthracite Area. Data on area disturbed in the Anthracite Fields are based on field reconnaissance and the measurement of the area indicated as disturbed on recent U.S.G.S. maps. Data on area disturbed in the Bituminous Fields are based on measurement of areas indicated as disturbed on U.S.G.S. maps, some of which were surveyed more than 30 years ago. Additional work is planned by the Project and cooperating agencies to more accurately determine the area disturbed in the Bituminous Fields.

Table 3 includes a tabulation of the area disturbed by mining and the estimated reclamation cost for the various counties of the five major areas considered in the Pennsylvania section of the Project area. No information is available for the Potomac River Basin portion of the Study Area; however, the disturbed area is not believed to be significant when compared to that studied in Pennsylvania.

The cost of lime neutralization of major acid contributors in the Study Area has been estimated by sub-basin. Major discharges to each sub-basin were identified and the costs of lime neutralization facilities to treat the individual discharges were estimated. In each sub-basin, an effort was made to include sufficient discharges in which the total net acidity contribution was greater than the maximum acid loading measured in the stream.

The capital cost of individual treatment plants was estimated with the aid of curves developed by Gannett, Fleming, Corddry and Carpenter, Inc., Consulting Engineers, Harrisburg, Pennsylvania. The curves were based upon preliminary designs of approximately 30 lime neutralization type mine drainage treatment plants of varying sizes. The preliminary cost estimate was made by the Consultant for each treatment plant on the basis of reinforced concrete units and sludge disposal by means of vacuum filtration and landfill disposal. None of the treatment facilities used to develop the curves has been built and the design estimate of costs has not been verified. It is believed, however, that the precision of the cost estimates determined from the curves falls well within the precision of the mine drainage source data available and the estimate of costs can be considered to be valid.

Available estimates of the cost of operation of lime neutralization mine drainage treatment facilities are based on very little actual experience. Most estimates vary between $0.30/1,000 gallons and $1.30/1,000 gallons. Estimates of mine drainage pollution abatement costs developed herein include the cost of operation of the treatment facilities for 10 years at the two extremes of treatment cost, $0.30/1,000 gallons and $1.30/1,000 gallons. Table 2 lists estimates of the total costs of construction and 10 years of operating the needed treatment facilities in each major division of the Study Area.

Table 3 lists the total estimated cost of reclamation and treatment in each major division of the Study Area in Pennsylvania.

The total estimated costs for construction and 10 years of operation of a treatment plant range from $258 million to $983 million, depending upon which one of the two extremes in treatment cost is applied. The estimated reclamation cost is $273 million. The total estimated expenditure required to abate and control mine drainage pollution in the Study Area over a 10-year period therefore ranges from $531 million to $1.2 billion. It should be noted that operating costs constitute a large percentage of the treatment costs.

REFERENCES

1. Draft Report to District Engineer, U. S. Army Engineer District, Baltimore, Maryland, August 17, 1966
2. Lorenz, Walter C., Mineral Industry Water Requirements and Waste Water in the Susquehanna River Basin. U. S. Bureau of Mines, 1966, 116 pp
3. Reese, J. F. and J. D. Sisler, Bituminous Coal Fields in Pennsylvania, Pennsylvania Topographic and Geologic Survey Bulletin MG pt 3, Harrisburg, Pennsylvania, 1928, 153 pp
4. Central Pennsylvania Coal Producers Association Estimate for January 1963
5. Wessel, William F., Mineral Resources in the Susquehanna River Basin, U. S. Bureau of Mines, 1966, 85 pp
6. Wessel, William F., Donald J. Frendzel, and Gabriel F. Cazell, Mineral Industry Economics in the Susquehanna River Basin, U. S. Bureau of Mines, 1964, 90 pp
7. Thomson, Rober D., Private Communication, December 1966

TABLE 2

ESTIMATED COST OF LIME NEUTRALIZATION TREATMENT OF MINE DRAINAGE CHESAPEAKE BAY-SUSQUEHANNA RIVER, AND DELAWARE RIVER BASINS

Sub-Basin	No. of Disch.	Flow (cfs)	Acid Load (#/Day)	Const. Cost 1/	Annual Operating Cost 1/ @ $0.30 1000 Gal	Annual Operating Cost 1/ @ $1.30 1000 Gal	10 Year Operating Cost 1/ @ $0.30 1000 Gal	10 Year Operating Cost 1/ @ $1.30 1000 Gal	Total Construct Plus 10 Year Operation @ $0.30 1000 Gal	Total Construct Plus 10 Year Operation @ $1.30 1000 Ga
West Branch Susquehanna										
1. West Branch upstream from Chest Creek	11	10.5	35,000	2.45	0.74	3.20	7.40	32.00	9.85	34.45
2. Chest Creek	1	1.0	---	0.22	0.07	0.31	0.70	3.10	0.92	0.53
3. Anderson Cr.	5	0.6	3,000	1.05	0.12	0.50	1.20	5.20	2.25	6.25
4. W. Br. Chest Cr. to Clearfield Creek	3	1.9	3,500	0.65	0.13	0.58	1.30	5.80	1.95	6.45
5. Clearfield Cr.	16	11.0	34,300	3.44	0.87	3.78	8.70	37.80	12.14	41.24
6. W. Br. Clearfield Creek to Moshannon Creek	7	17.6	36,400	1.62	1.04	4.53	10.40	45.30	12.02	46.92
7. Moshannon Cr.	32	24.9	139,100	6.93	1.95	8.47	19.50	84.70	26.43	91.63
8. Sinnemahoning	4	5.9	30,000	0.89	0.42	1.82	4.20	18.20	5.09	19.09
9. Cooks Run	1	3.8	7,300	0.25	0.27	1.18	2.70	11.80	2.95	12.05
10. Kettle Creek	1	2.0	15,000	0.23	0.14	0.62	1.40	6.20	1.63	6.43
11. N. Bald Eagle	6	3.1	9,600	1.29	0.22	0.94	2.22	9.40	3.51	10.69
Sub Total	87	82.3	313,200	19.02	5.98	25.93	59.80	259.80	78.82	278.82

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Sub-Basin	No. of Disch.	Flow (cfs)	Acid Load (#/Day)	Const. Cost 1/	Annual Operating Cost 1/ @ $0.30 1000 Gal	Annual Operating Cost 1/ @ $1.30 1000 Gal	10 Year 1/ Operating Cost @ $0.30 1000 Gal	10 Year 1/ Operating Cost @ $1.30 1000 Gal	Total Construction Plus 10 Year 1/ Operation @ $0.30 1000 Gal	Total Construction Plus 10 Year 1/ Operation @ $1.30 1000 Gal
Tioga	4	3.4	16,900	0.87	0.24	1.03	2.40	10.30	3.27	11.17
Juniata	6	24.5	27,000	1.55	1.73	7.48	1.73	74.80	3.28	76.35
Anthracite Area										
Susquehanna Basin										
1. Lackawanna	2	141.2	60,000	4.50*	1.08*	4.69*	10.80	46.90	15.30	51.40
2. Susquehanna	17	138.1	460,000	18.90*	0.83*	3.60	8.30	36.00	27.20	54.90
3. Nescopeck	3	31.3	99,200	0.76	2.22	9.60	22.20	96.0	22.96	96.76
4. Catawissa	3	16.7	1,140	0.66	1.18	5.10	11.80	51.0	12.46	51.66
5. Shamokin	7	27.3	37,650	2.64	1.93	8.39	19.3	83.9	21.94	86.54
6. Mahanoy	7	39.2	Alkaline	3.01	1.89	8.21	18.9	82.1	21.91	85.11
7 Mahantango	1	7.5	5,800	0.34	0.53	2.30	5.30	23.0	5.64	23.34
8. Wiconisco	2	1.1	900	0.22	0.08	0.35	0.80	3.5	1.02	3.72
9. Swatara	6	9.5	4,600	1.19	0.67	2.92	6.70	29.2	7.89	30.39
Sub Total	48	411.9	669,290	30.22	10.42	45.16	104.20	451.60	134.42	481.82

(Continued)

Sub-Basin	No. of Disch.	Flow (cfs)	Acid Load (#/Day)	Const. Cost 1/	Annual Operating Cost 1/ @ $0.30 1000 Gal	Annual Operating Cost 1/ @ $1.30 1000 Gal	10 Year 1/ Operating Cost @ $0.30 1000 Gal	10 Year 1/ Operating Cost @ $1.30 1000 Gal	Total Construct Plus 10 Year Operation @ $0.30 1000 Gal	Total Construct Plus 10 Year Operation @ $1 1000
Delaware Basin										
1. Lehigh River	10	6.3	13,800	2.17	0.44	1.92	4.40	19.2	6.57	21
2. Schuylkill River	29	31.9	36,200	6.69	2.47	10.73	24.70	107.3	31.39	113
Sub Total		38.2	50,000	8.86	2.92	12.65	29.20	126.5	38.06	135
Potomac Basin**										
Grand Total	184	560.3	1,076,390	60.52	21.29	92.25	212.9	922.5	257.9	983

1/ Millions of Dollars

* Based on preliminary design figures

** Data not presently available

TABLE 3

ESTIMATED MINE DRAINAGE POLLUTION ABATEMENT COST
CHESAPEAKE BAY-SUSQUEHANNA RIVER AND DELAWARE RIVER BASINS

Area	County	(Acres) Disturbed Area	Reclamation Cost (Millions of Dollars)	Lime Neutralization Cost - Ten Years Millions of Dollars @ $0.30 1000 Gal	Lime Neutralization Cost - Ten Years Millions of Dollars @ $1.30 1000 Gal	Total Cost Ten-Year Program Millions of Dollars @ $0.30 1000 Gal	Total Cost Ten-Year Program Millions of Dollars @ $1.30 1000 Gal
West Branch Susquehanna River							
	Cambria	31,150	15.6				
	Cameron	100	0.1				
	Centre	10,466	5.2				
	Clearfield	42,000	21.0				
	Clinton	12,500	6.3				
	Elk 1/	1,230	0.6				
	Indiana 2/	1,700	0.9				
	Lycoming	280	0.1				
Sub-Total		99,426	49.8	78.82	278.82	128.6	328.6
Juniata River Basin							
	Bedford	2,000	1.0				
	Blair	3,000	1.5				
	Fulton	400	0.2				
	Huntingdon	15,000	7.5				
Sub-Total		20,400	10.2	3.27	11.17	13.5	21.4
Tioga River Basin	Tioga	4,500	2.3	3.28	76.36	5.6	78.7
Anthracite Area Susquehanna River Basin							
	Carbon	2,600	6.5				
	Columbia	2,565	6.4				
	Dauphin	434	1.1				
	Lackawanna	11,200	28.0				

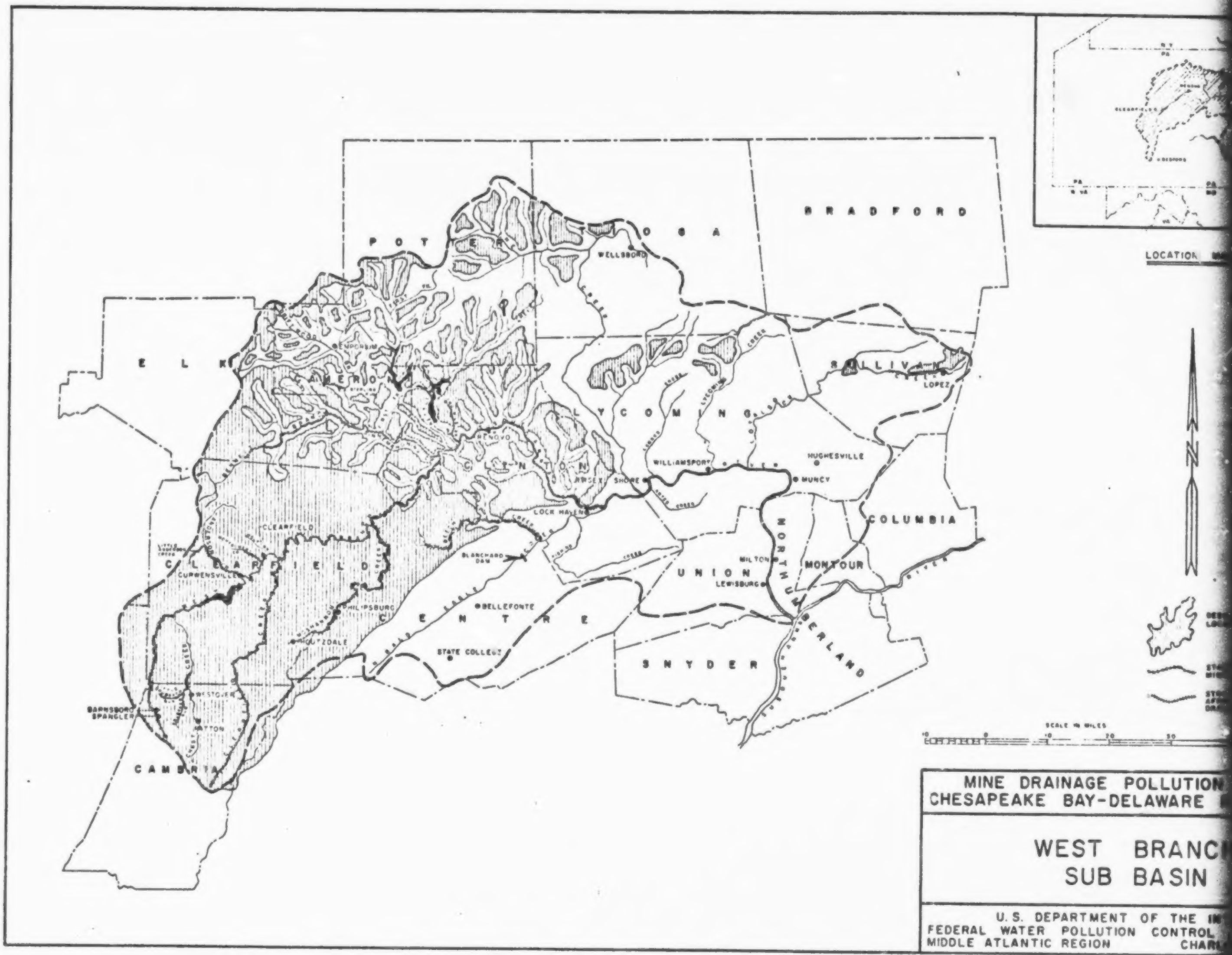
TABLE 3 (Continued)

Area	County	(Acres) Disturbed Area	Reclamation Cost (Millions of Dollars)	Lime Neutralization Cost - Ten Years Millions of Dollars @ $0.30 1000 Gal	Lime Neutralization Cost - Ten Years Millions of Dollars @ $1.30 1000 Gal	Total Cost Ten-Year Program Millions of Dollars @ $0.30 1000 Gal	Total Cost Ten-Year Program Millions of Dollars @ $1.30 1000 Gal
Susquehanna River Basin (Continued)							
	Lebanon	221	0.6				
	Luzerne	21,300	53.3				
	Northumberland	9,600	24.0				
	Schuylkill	18,100	45.3'				
	Susquehanna	143	0.4				
	Wayne	67	0.2				
Sub-Total		66,230	165.8	134.42	481.82	300.2	647.6
Delaware River Basin							
	Carbon	950	2.4				
	Schuylkill	16,995	42.5				
Sub-Total		17,945	44.9	38.06	135.36	44.8	142.1
Potomac River Basin 3/		—	—	—	—	—	—
Grand Total		208,501	273.0	257.9	983.12	530.9	1256.0

1/ 35% of area in Basin

2/ 10% of area in Basin.

3/ Data not presently available.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JERSEY SHORE
LOCK HAVEN
COLUMBIA
CLEARFIELD
CURWENSVILLE
BLANCHARD DAM
PHILIPSBURG
BELLEFONTE
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HOUTZDALE
CENTRE
STATE COLLEGE
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MILTON
LEWISBURG
MONTOUR
NORTHUMBERLAND
SNYDER
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LOCATION MAP
SCALE IN MILES
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MINE DRAINAGE POLLUTION
CHESAPEAKE BAY-DELAWARE

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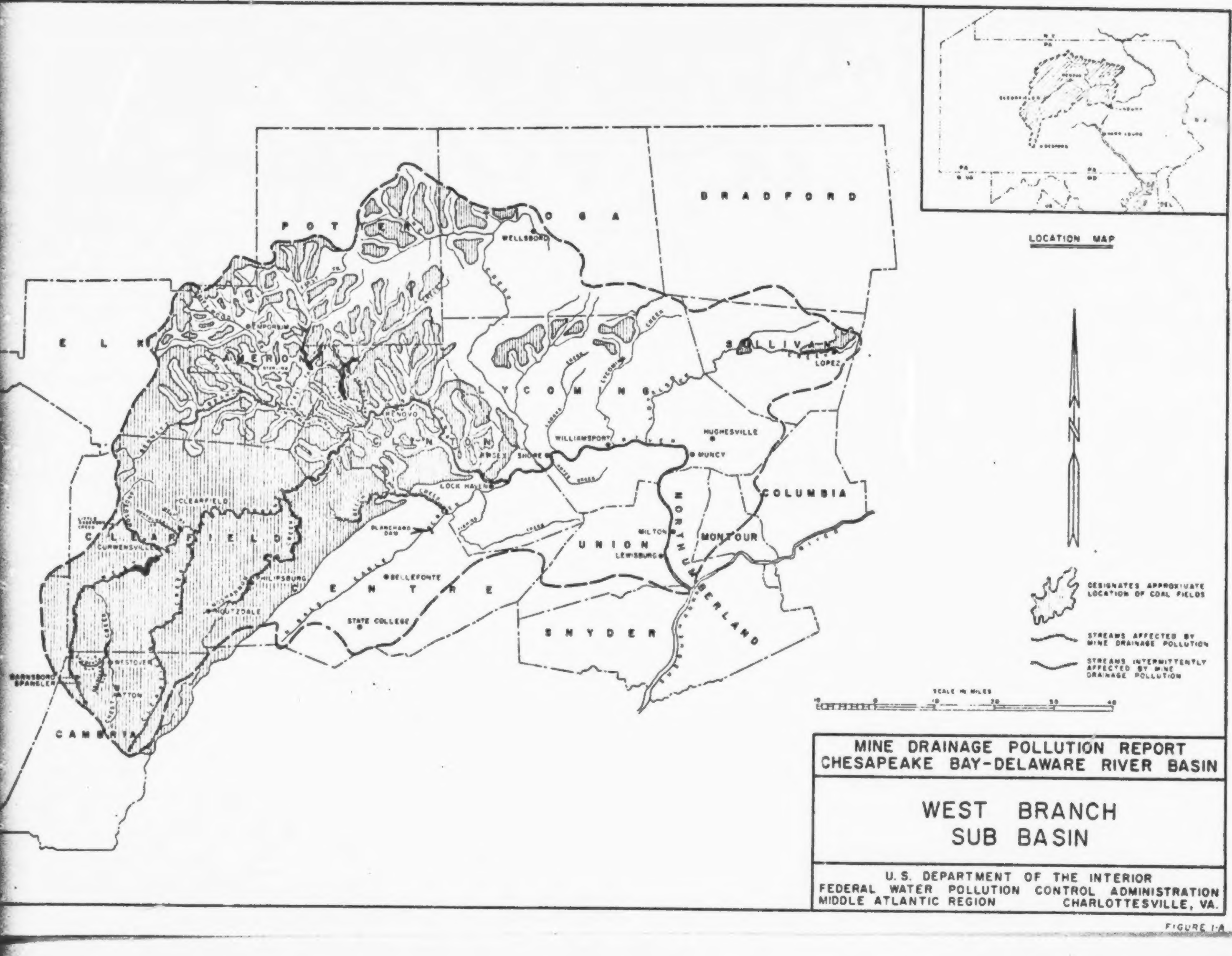
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DESIGNATES APPROXIMATE LOCATION OF COAL FIELDS
STREAMS AFFECTED BY MINE DRAINAGE POLLUTION
STREAMS INTERMITTENTLY AFFECTED BY MINE DRAINAGE POLLUTION
SCALE IN MILES
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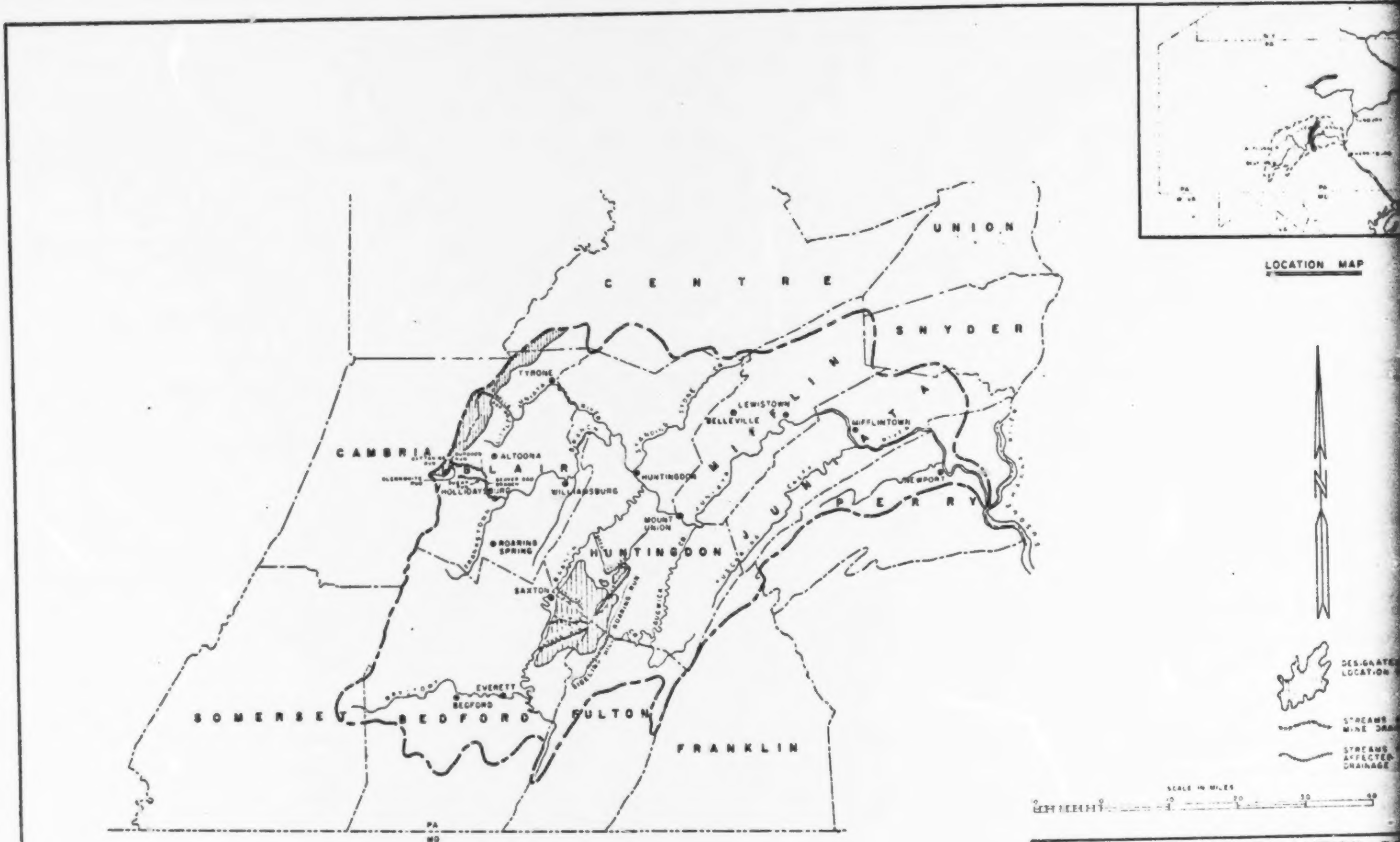
MINE DRAINAGE POLLUTION REPORT
CHESAPEAKE BAY-DELAWARE RIVER BASIN

WEST BRANCH
SUB BASIN

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
MIDDLE ATLANTIC REGION CHARLOTTESVILLE, VA.

FIGURE I-A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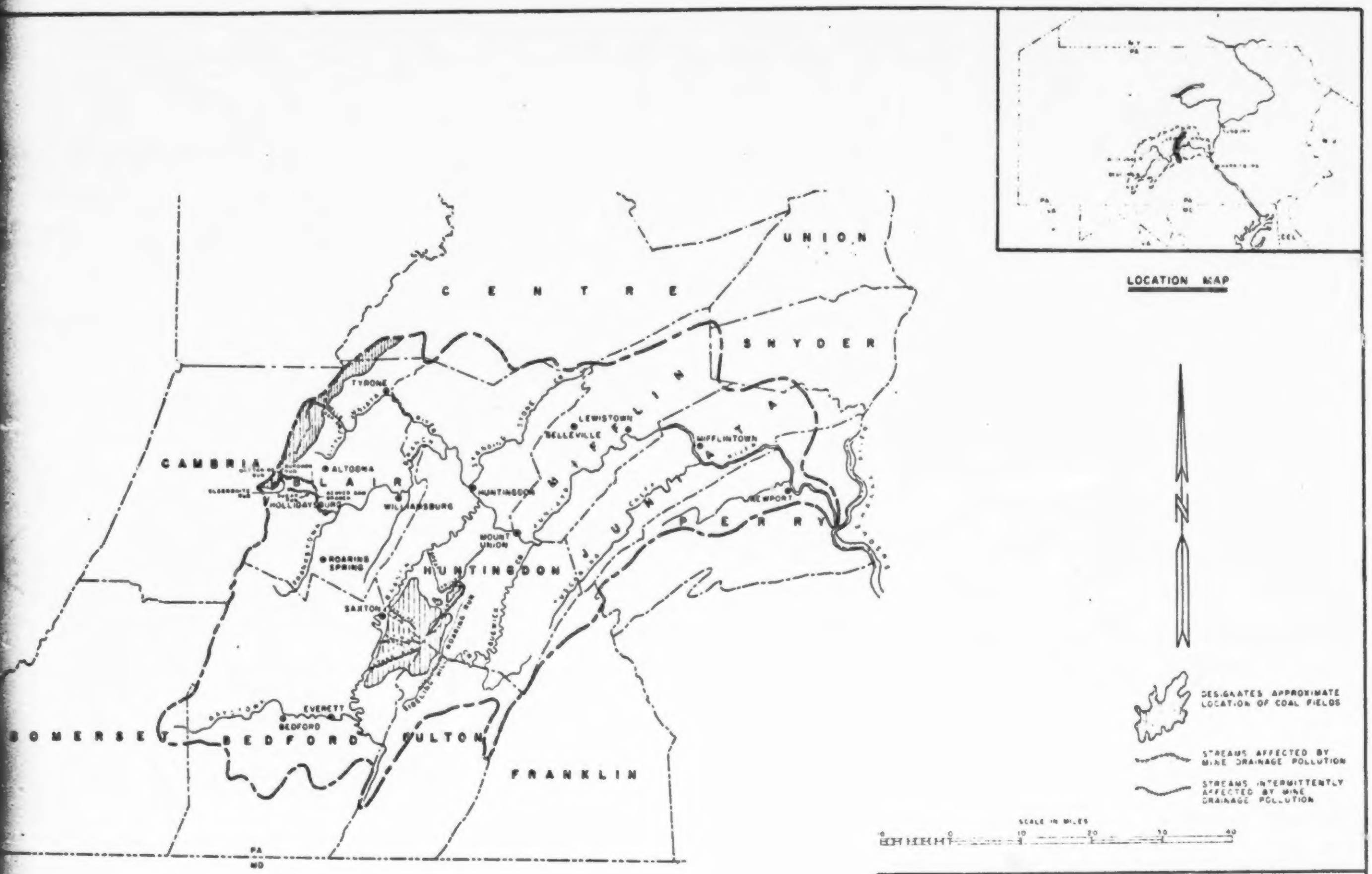
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STREAMS INTERMITTENTLY AFFECTED BY MINE DRAINAGE POLLUTION
SCALE IN MILES
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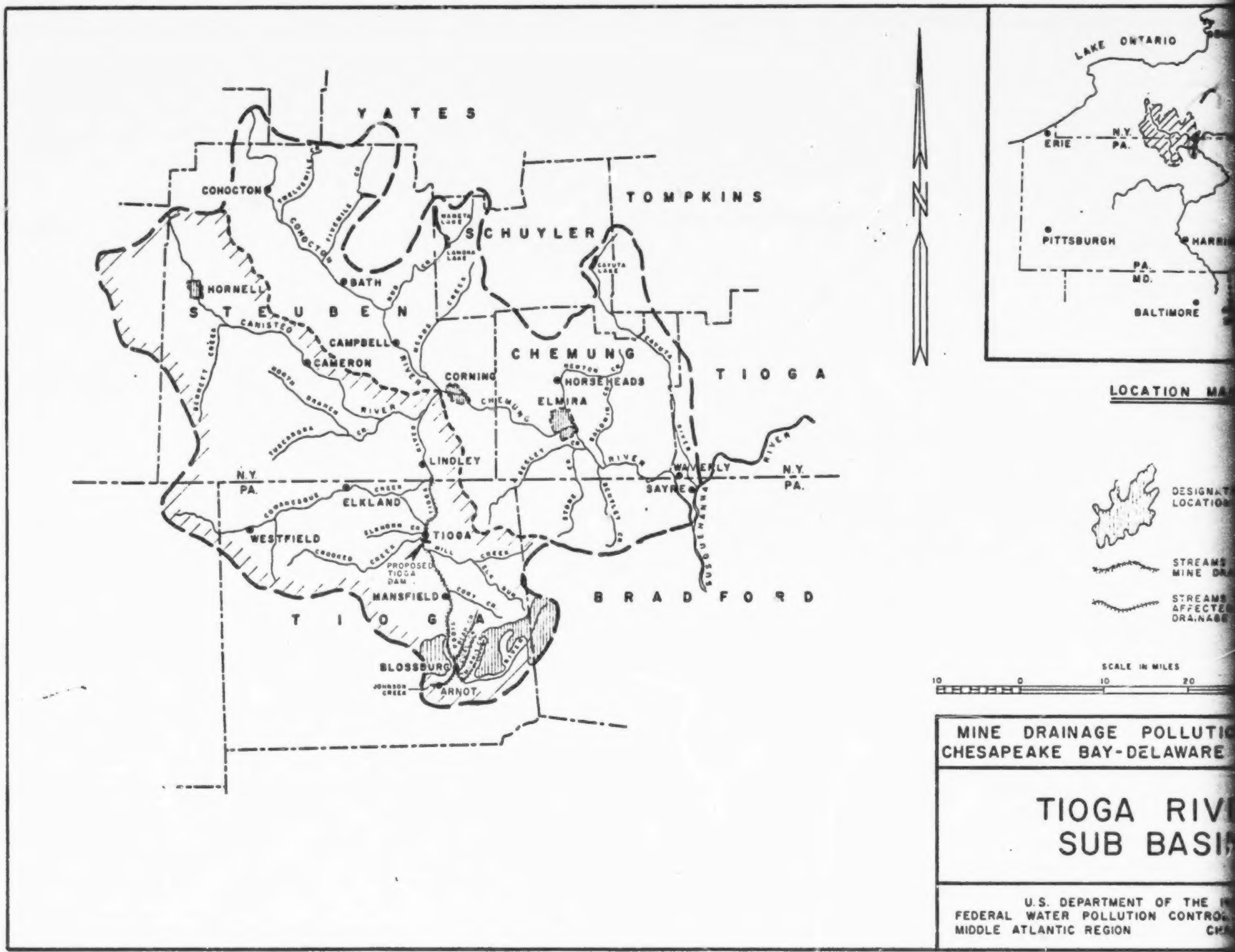
MINE DRAINAGE POLLUTION REPORT
CHESAPEAKE BAY-DELAWARE RIVER BASIN

JUNIATA RIVER SUB-BASIN

U. S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
MIDDLE ATLANTIC REGION CHARLOTTESVILLE, VA.

FIGURE I-8



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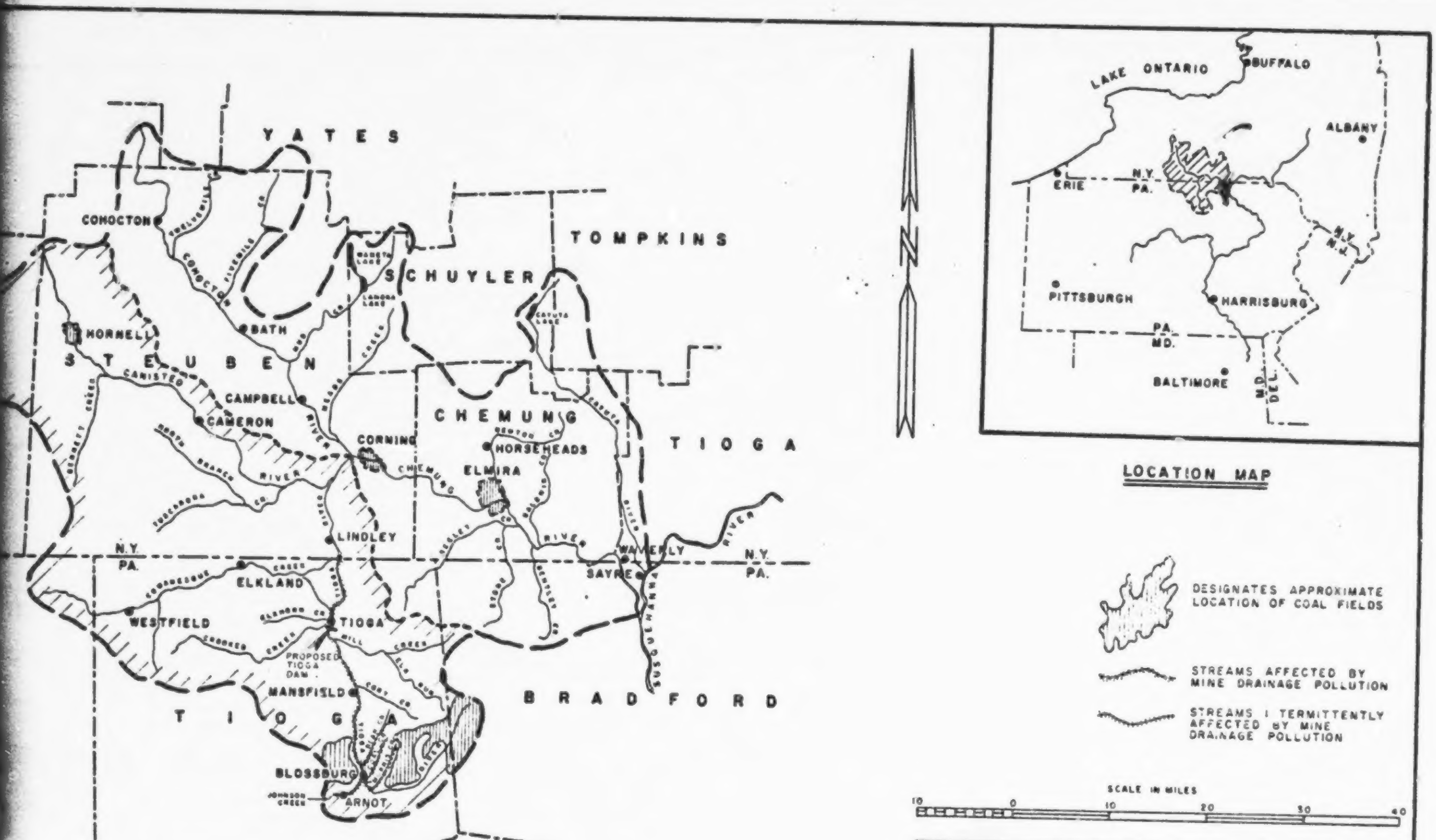
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LOCATION MAP
DESIGNATES APPROXIMATE LOCATION OF COAL FIELDS
STREAMS AFFECTED BY MINE DRAINAGE POLLUTION
STREAMS INTERMITTENTLY AFFECTED BY MINE DRAINAGE POLLUTION
SCALE IN MILES
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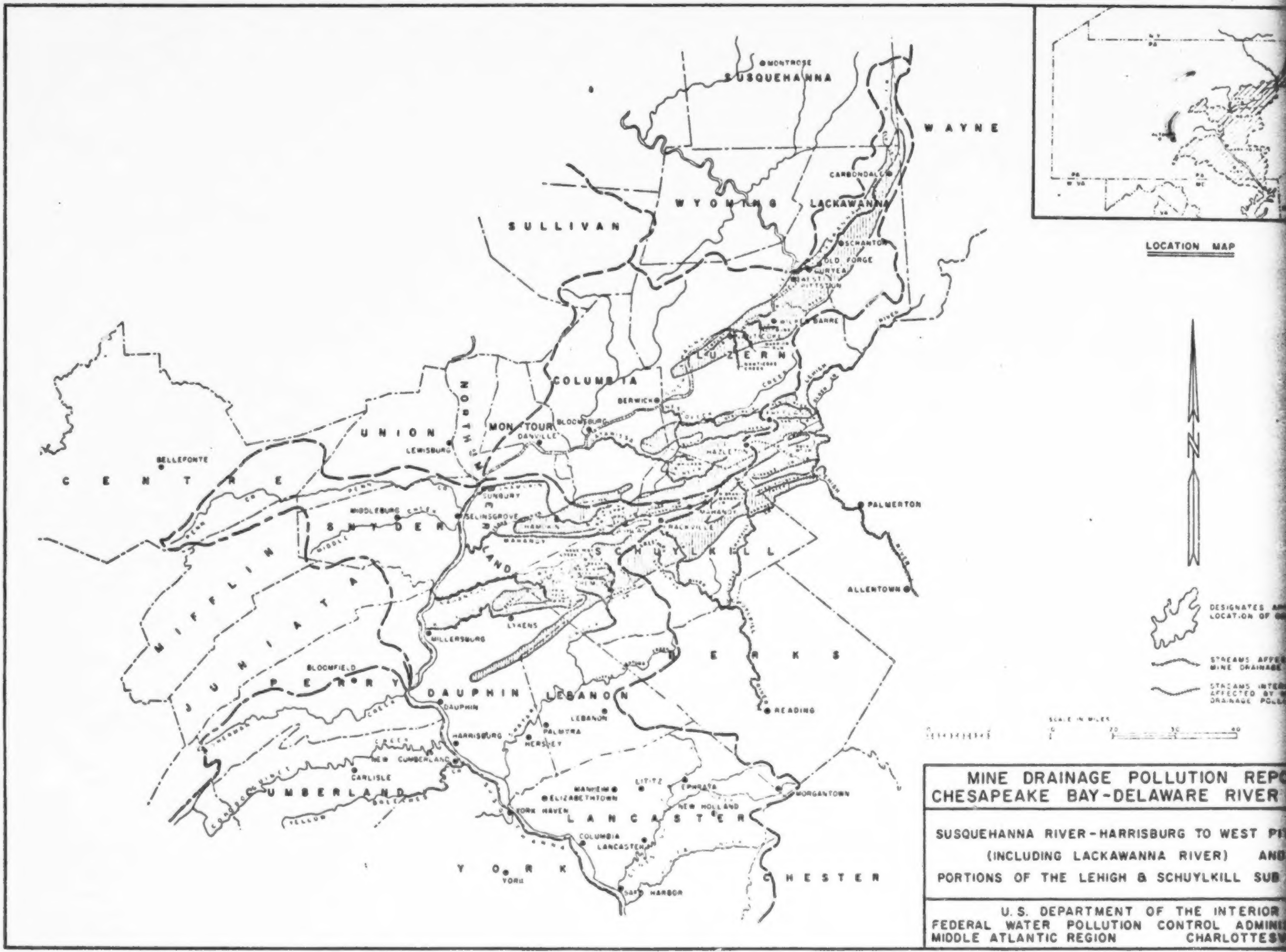
MINE DRAINAGE POLLUTION REPORT
CHESAPEAKE BAY-DELAWARE RIVER BASIN

TIOGA RIVER SUB BASIN

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
MIDDLE ATLANTIC REGION CHARLOTTESVILLE, VA.

FIGURE I-C


LOCATION MAP
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WILKES-BARRE
LUZERNE
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NORTHUMBERLAND
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SCHUYLKILL
PALMERTON
ALLENTOWN
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JUNIATA
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LYKENS
BLOOMFIELD
PERRY
DAUPHIN
LEBANON
BERKS
READING
HARRISBURG
PALMYRA
HERSHEY
NEW CUMBERLAND
CARLISLE
CUMBERLAND
YORK HAVEN
MANHEIM
ELIZABETHTOWN
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MINE DRAINAGE POLLUTION REPO
CHESAPEAKE BAY-DELAWARE RIVER

SUSQUEHANNA RIVER-HARRISBURG TO WEST PI
(INCLUDING LACKAWANNA RIVER) AND
PORTIONS OF THE LEHIGH & SCHUYLKILL SUB

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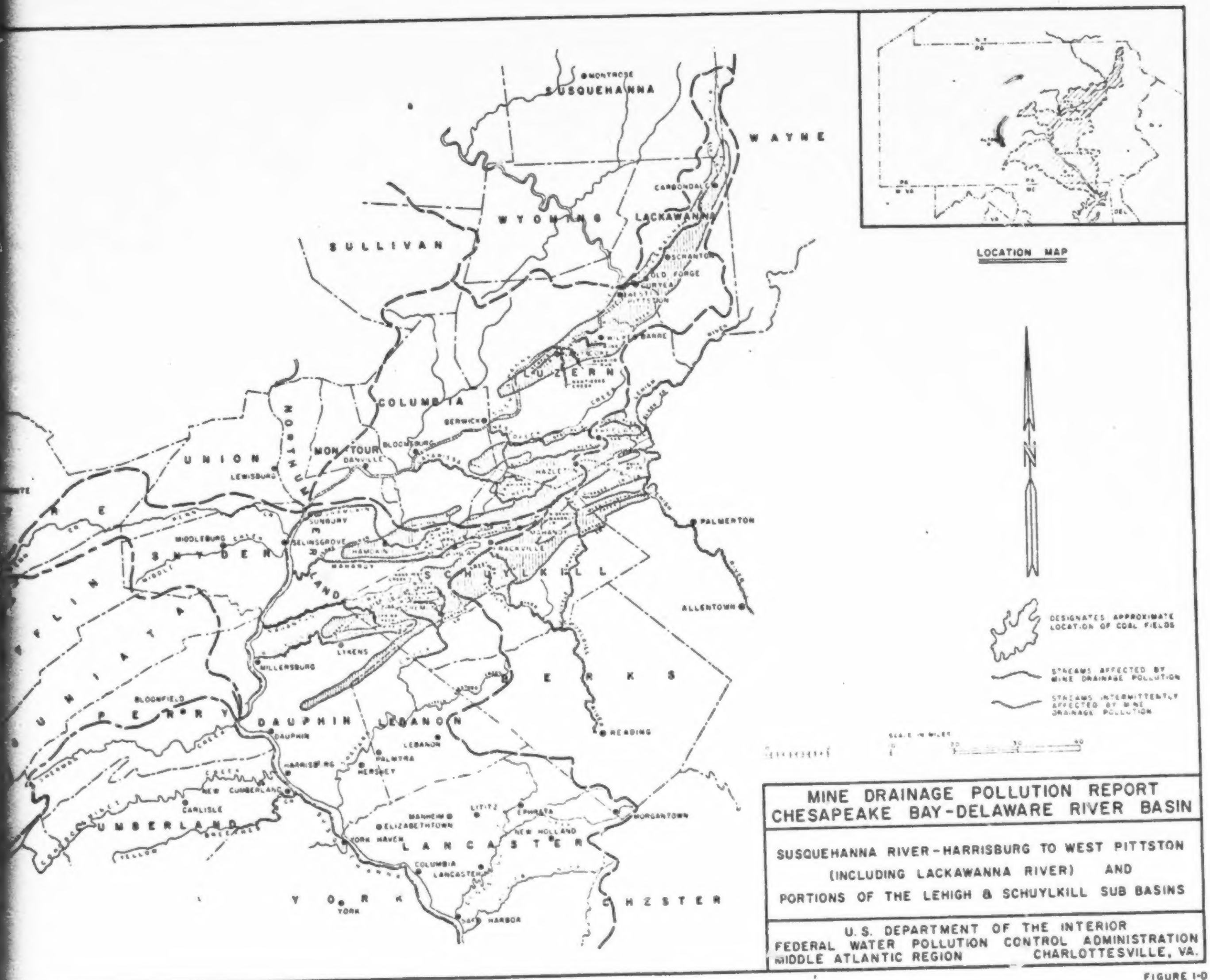
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ALLENTOWN
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COLUMBIA
YORK
SAFE HARBOR
CHESTER
LOCATION MAP
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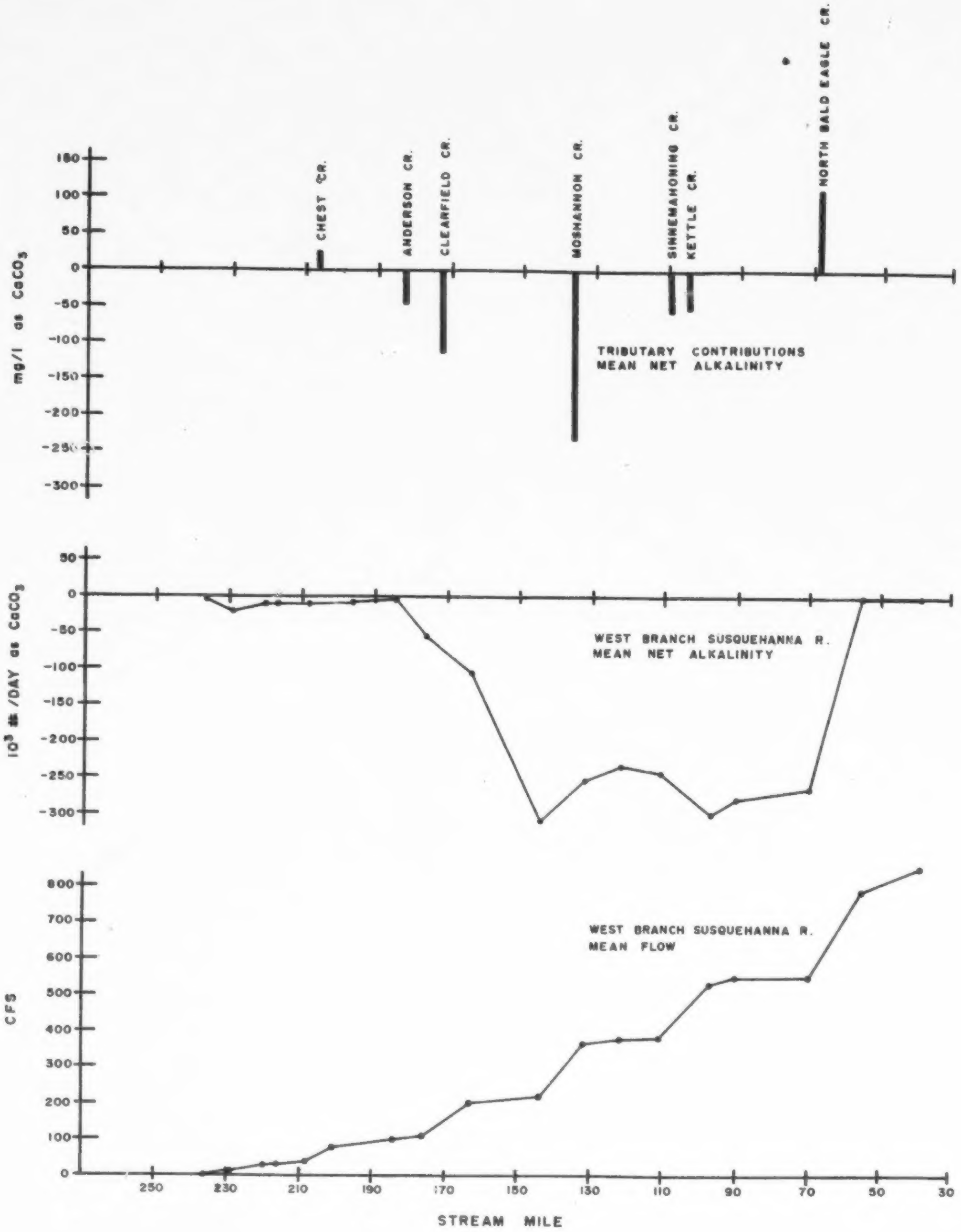
DESIGNATES APPROXIMATE LOCATION OF COAL FIELDS
STREAMS AFFECTED BY MINE DRAINAGE POLLUTION
STREAMS INTERMITTENTLY AFFECTED BY MINE DRAINAGE POLLUTION
SCALE IN MILES

MINE DRAINAGE POLLUTION REPORT
CHESAPEAKE BAY-DELAWARE RIVER BASIN

SUSQUEHANNA RIVER-HARRISBURG TO WEST PITTSTON
(INCLUDING LACKAWANNA RIVER) AND
PORTIONS OF THE LEHIGH & SCHUYLKILL SUB BASINS

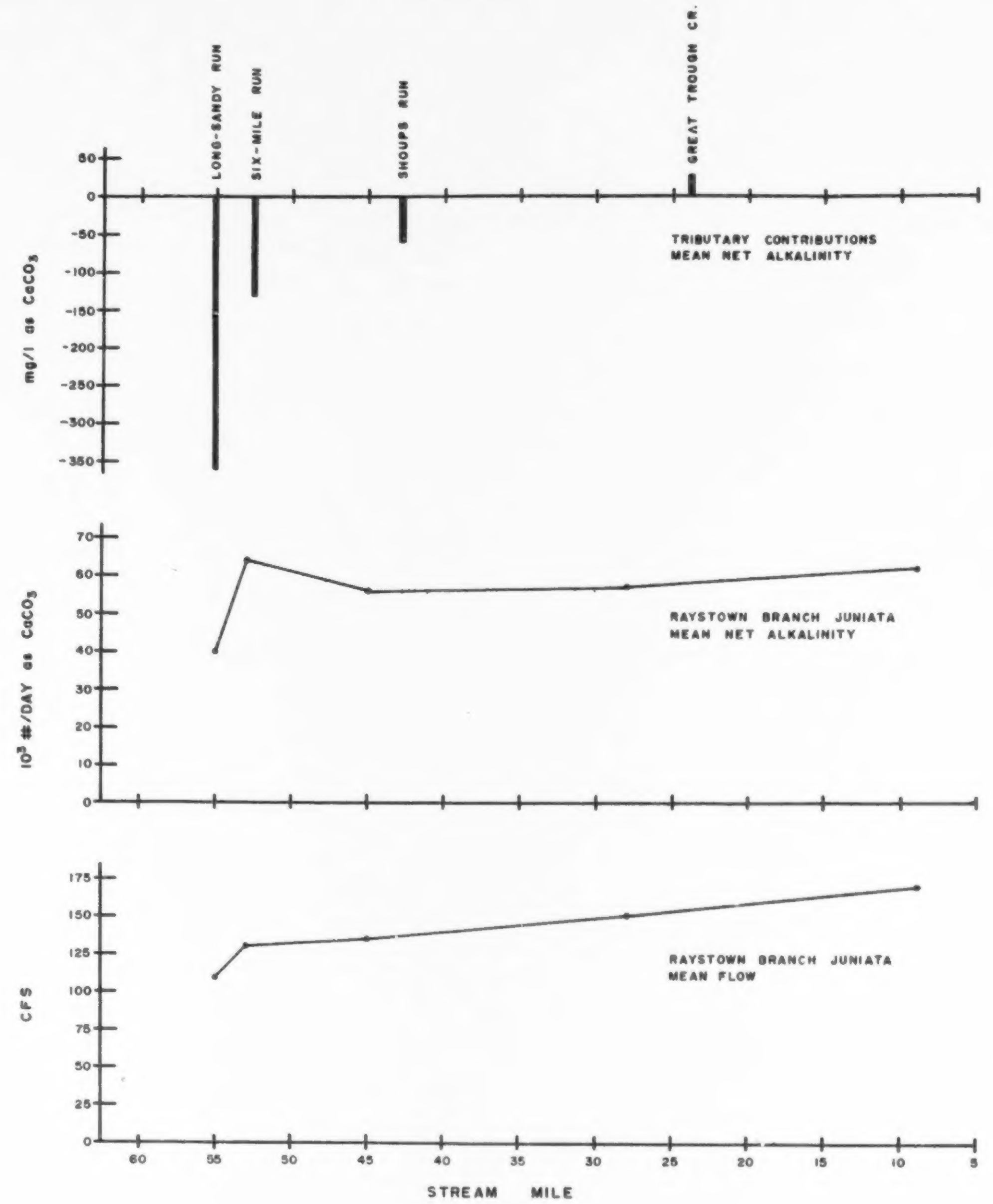
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
MIDDLE ATLANTIC REGION CHARLOTTESVILLE, VA.

FIGURE I-D



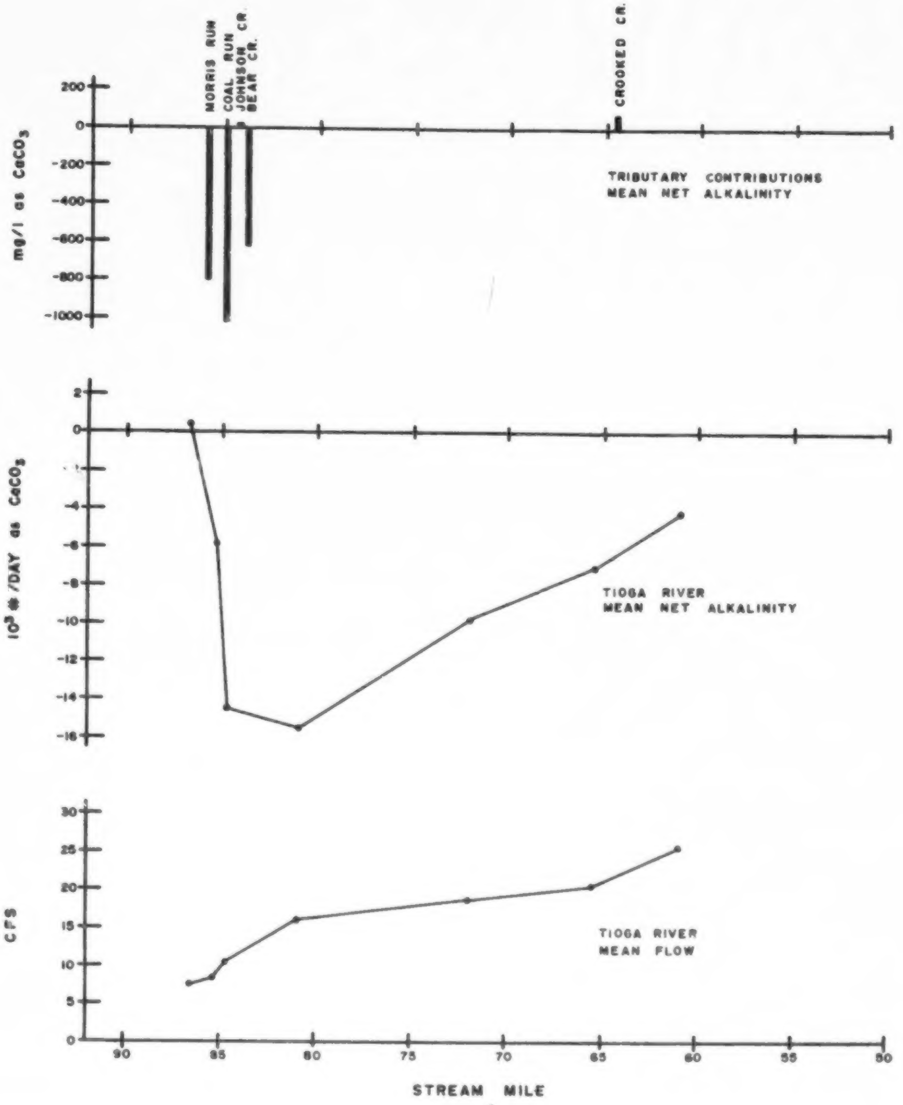
PROFILE OF FLOW, NET ALKALINITY OF WEST BRANCH SUSQUEHANNA RIVER
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

FIGURE 2



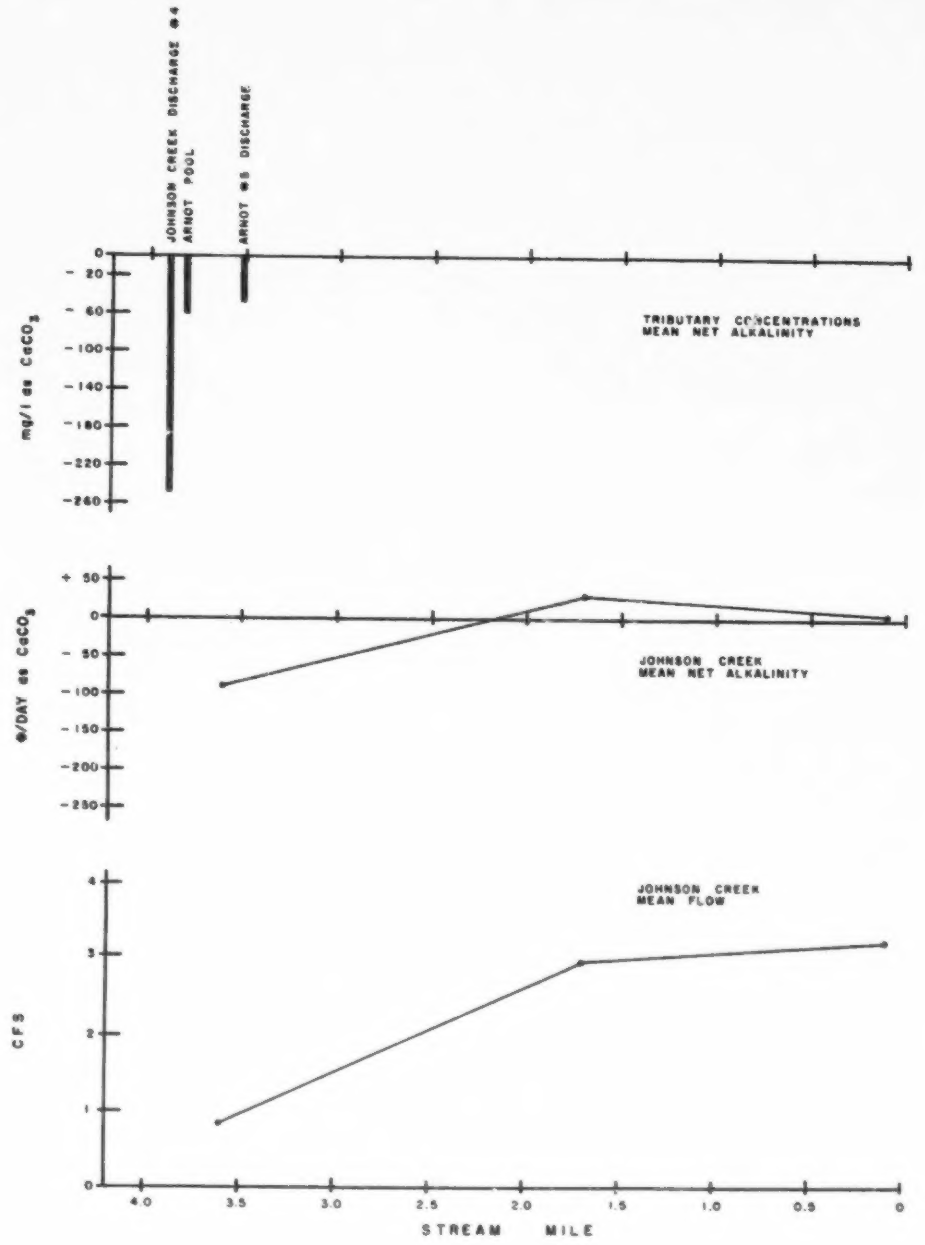
PROFILE OF FLOW, NET ALKALINITY OF RAYSTOWN BRANCH JUNIATA RIVER
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

FIGURE 3



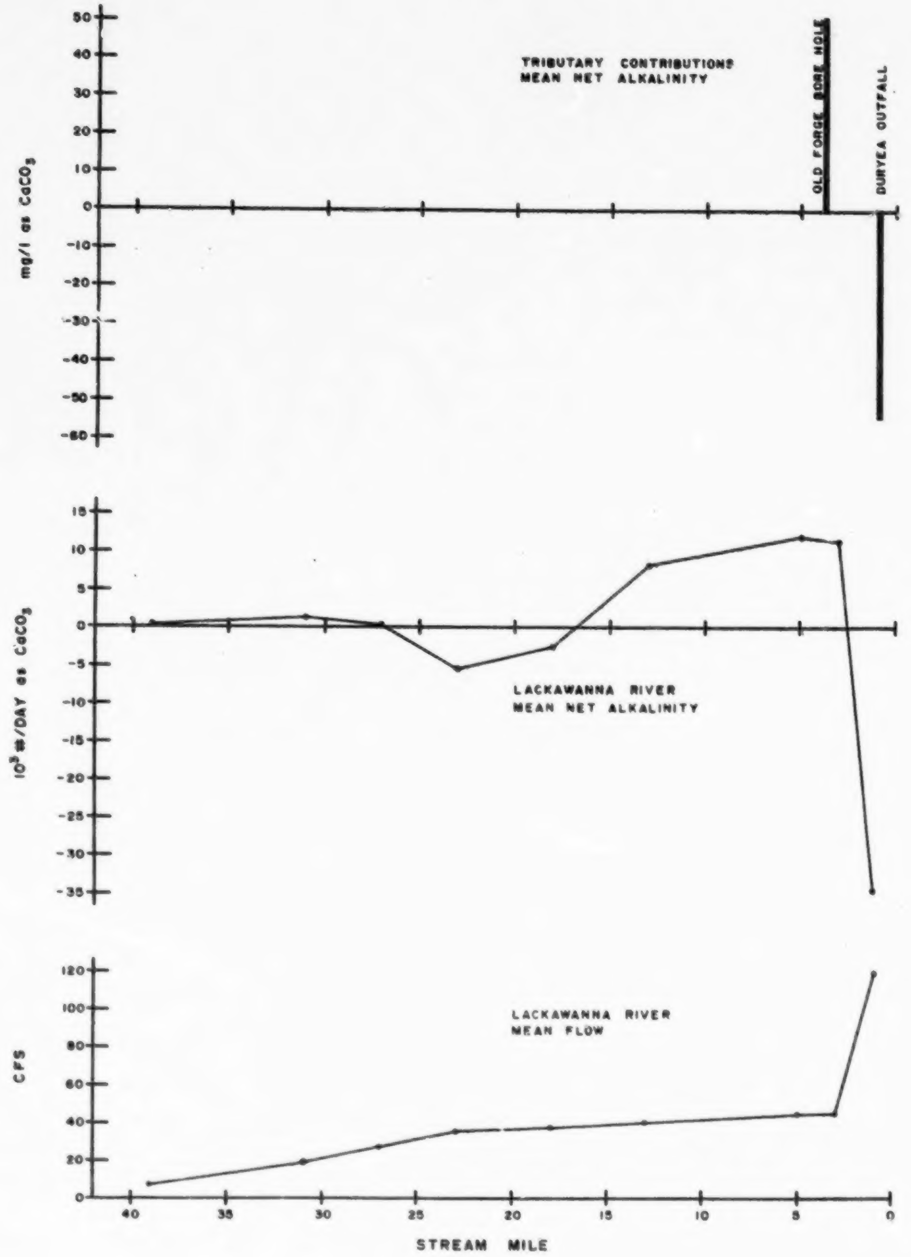
PROFILE OF FLOW, NET ALKALINITY OF TIOGA RIVER
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

FIGURE 4



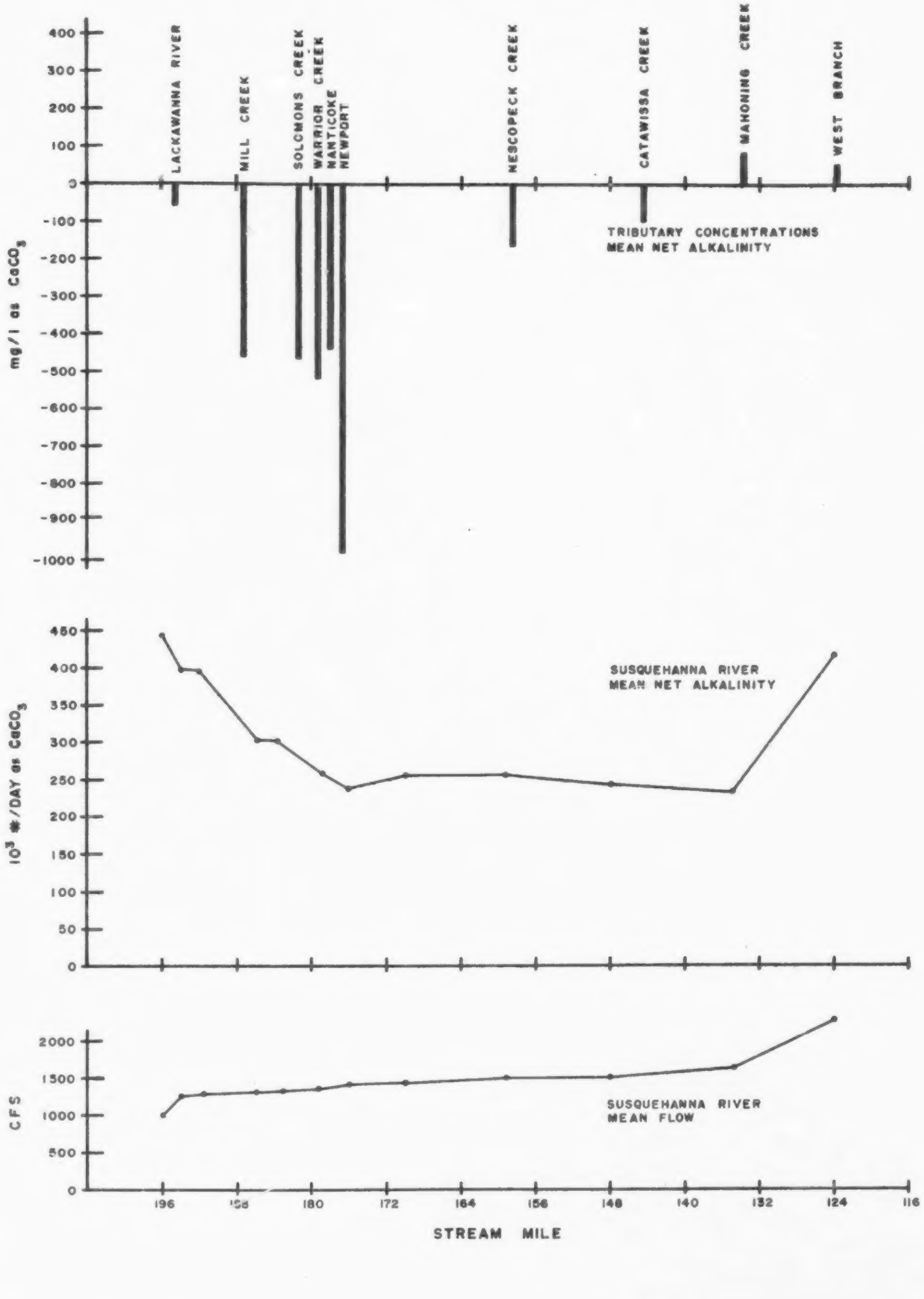
PROFILE OF FLOW, NET ALKALINITY OF JOHNSON CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

FIGURE 5



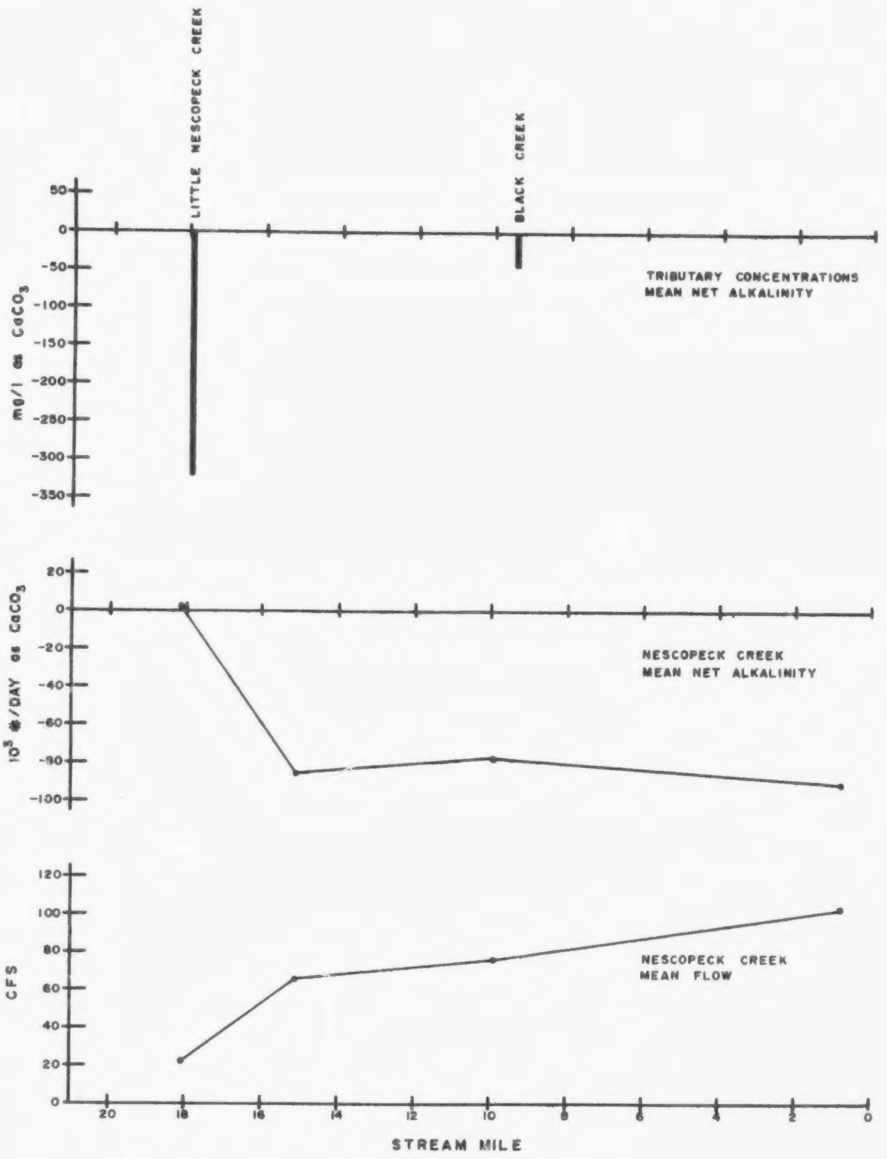
PROFILE OF FLOW, NET ALKALINITY OF LACKAWANNA RIVER
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

FIGURE 6



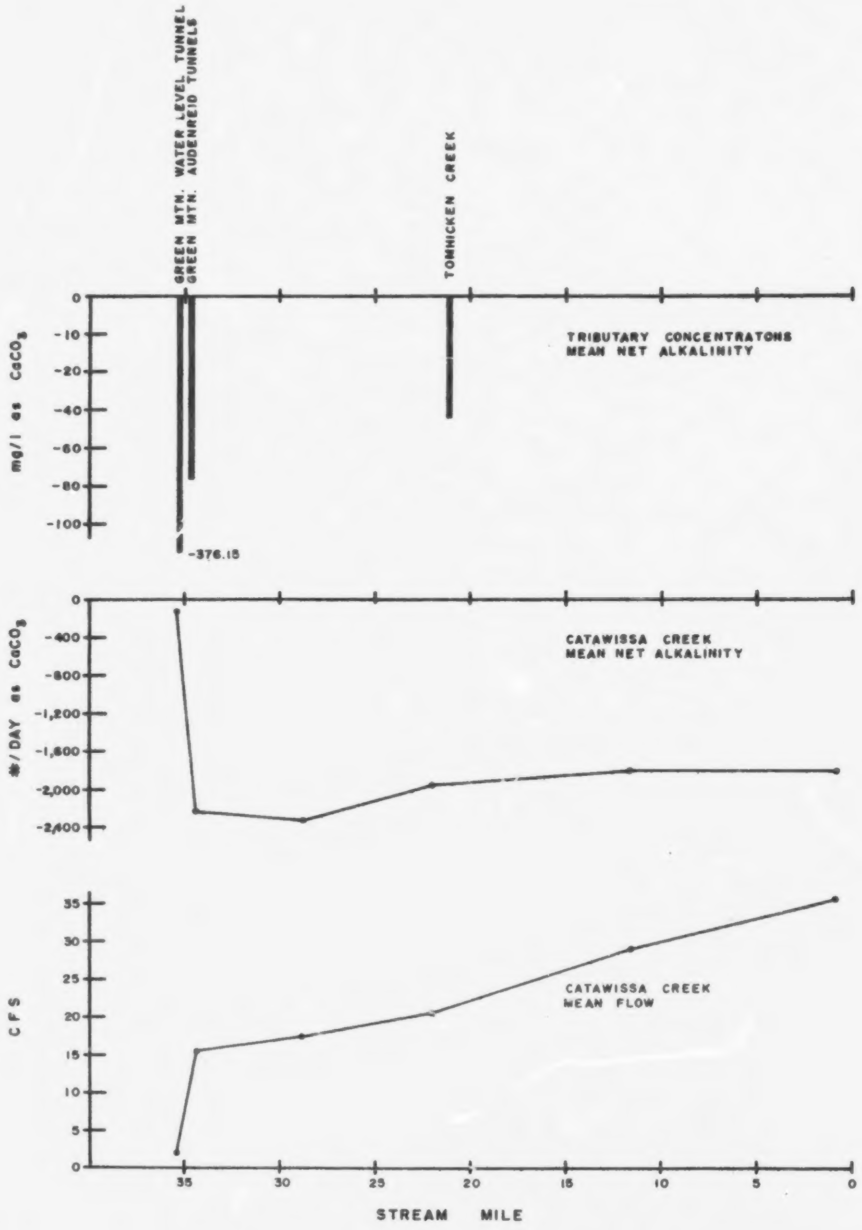
PROFILE OF FLOW, NET ALKALINITY OF SUSQUEHANNA RIVER
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

FIGURE 7



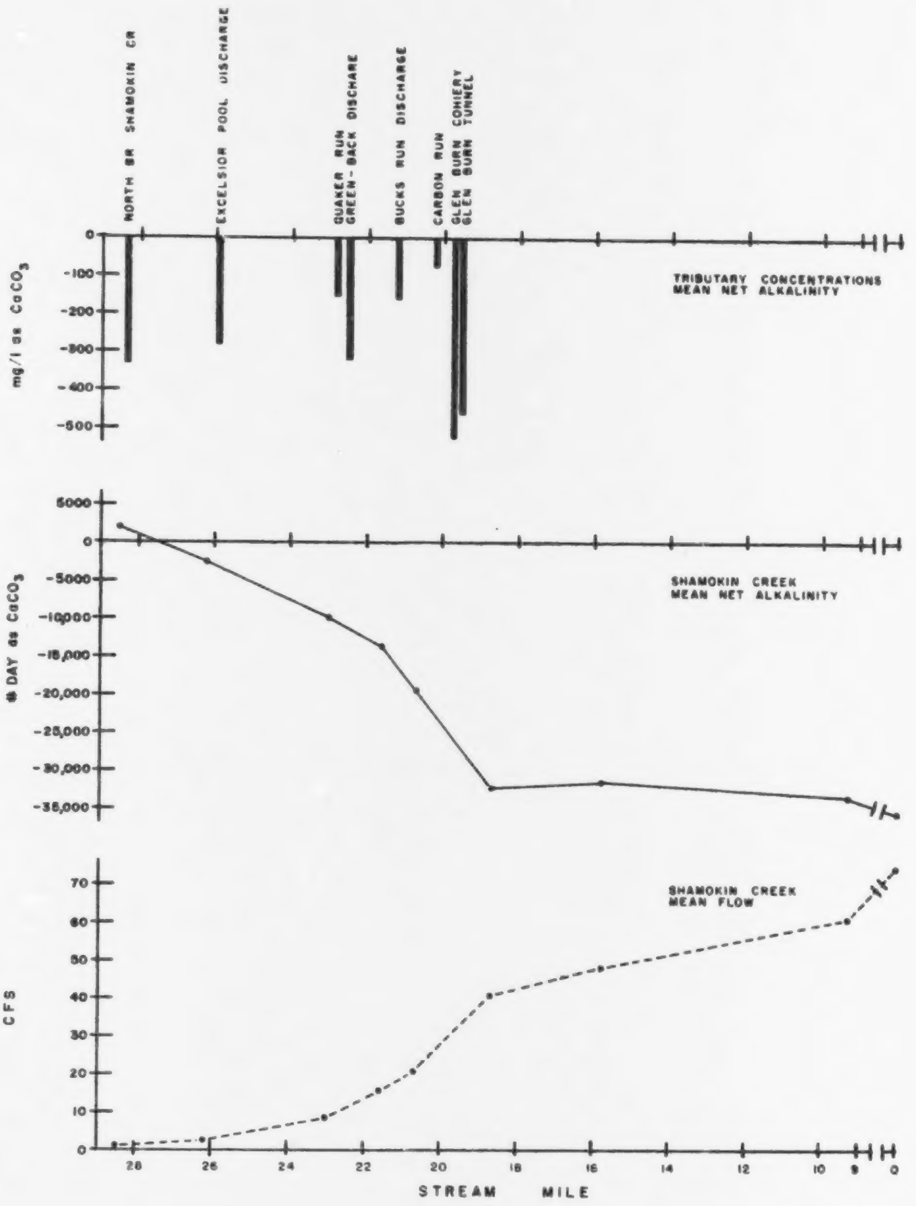
PROFILE OF FLOW, NET ALKALINITY OF NESCOPECK CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

FIGURE 8



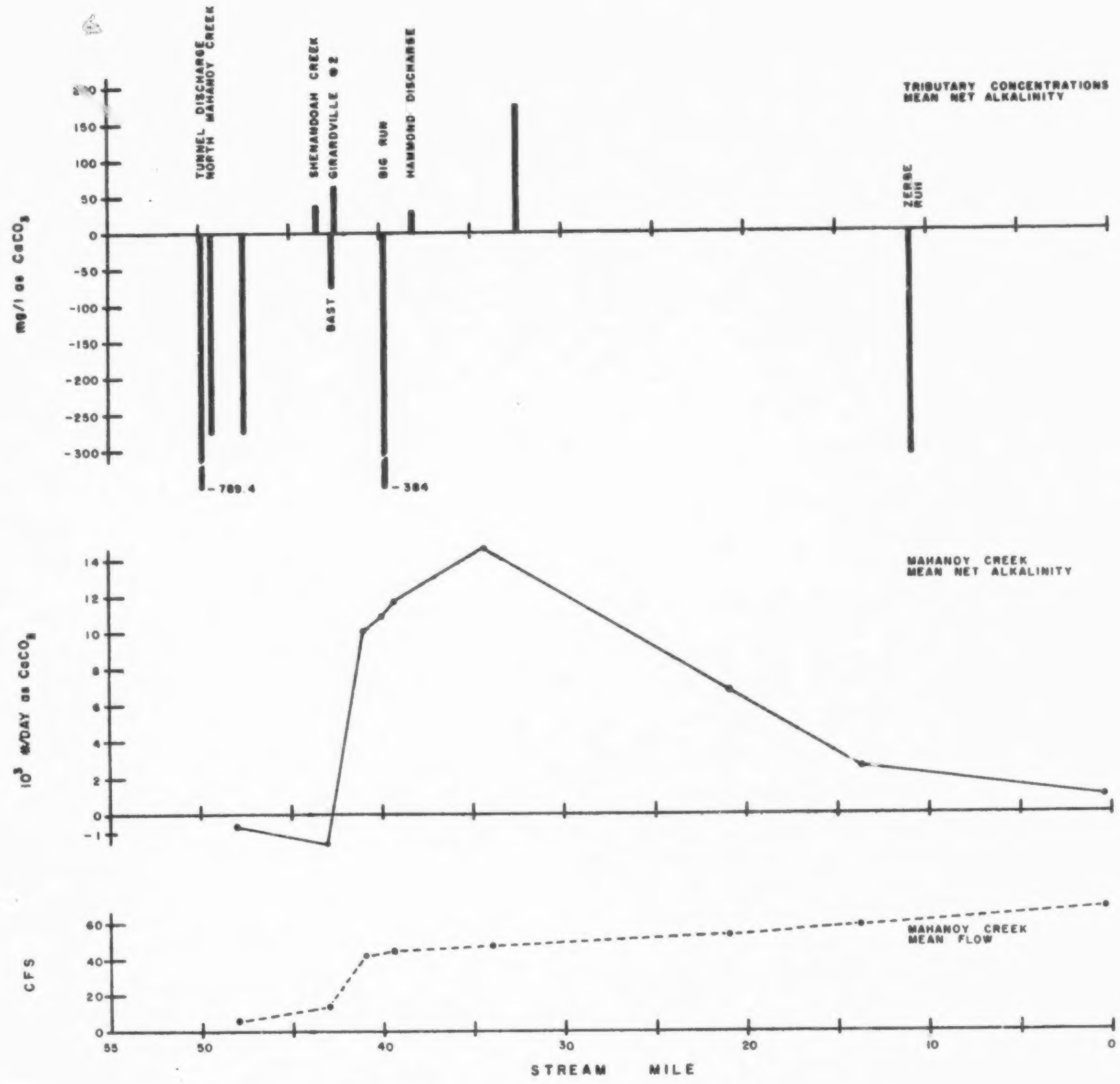
PROFILE OF FLOW, NET ALKALINITY OF CATAWISSA CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

FIGURE 9



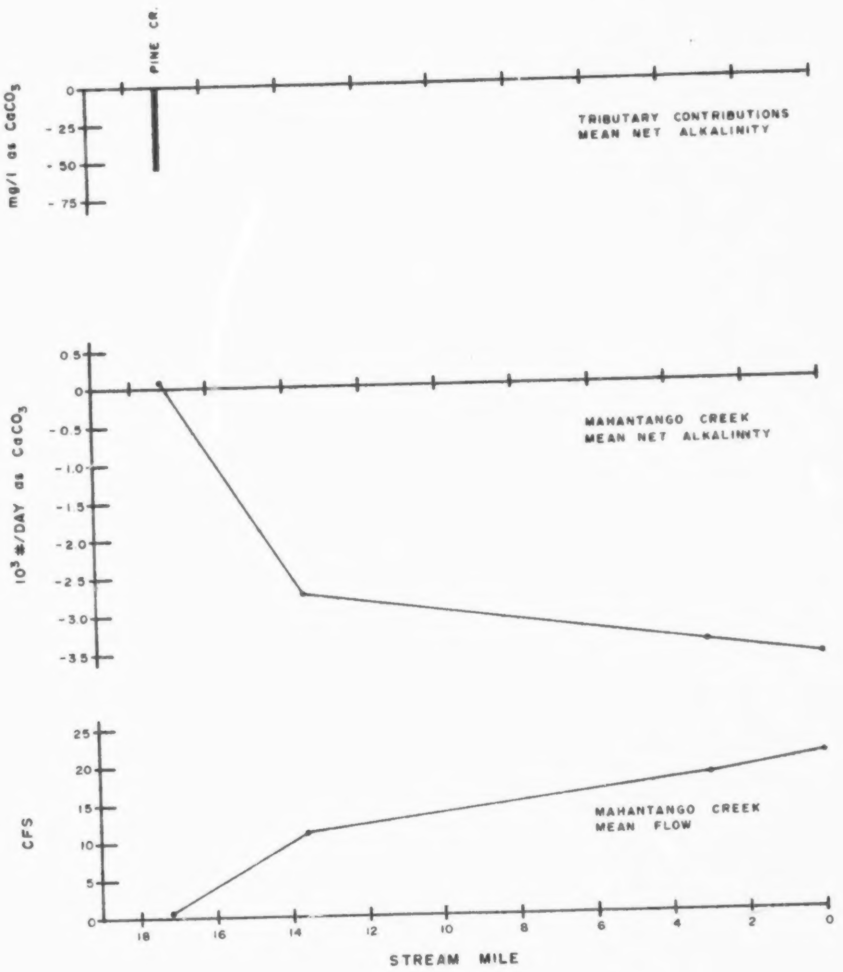
PROFILE OF FLOW, NET ALKALINITY OF SHAMOKIN CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

FIGURE 10



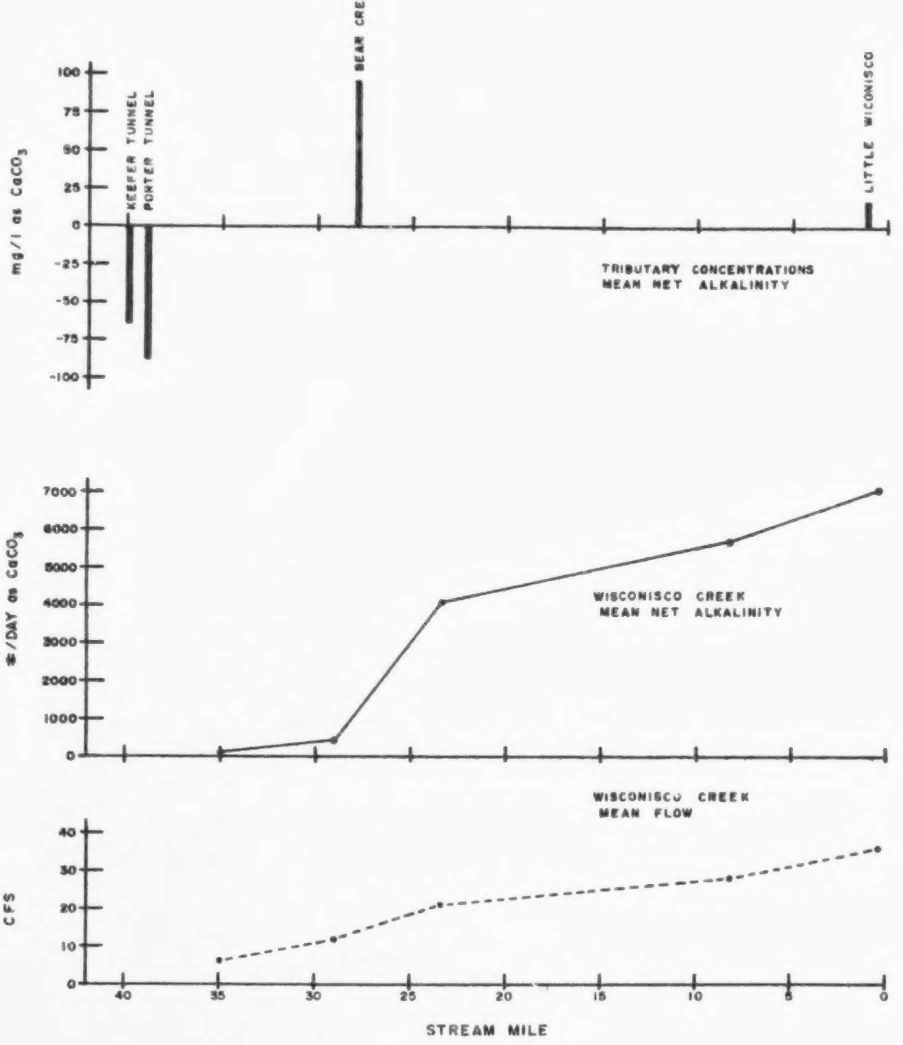
PROFILE OF FLOW, NET ALKALINITY OF MAHANOY CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

FIGURE 11



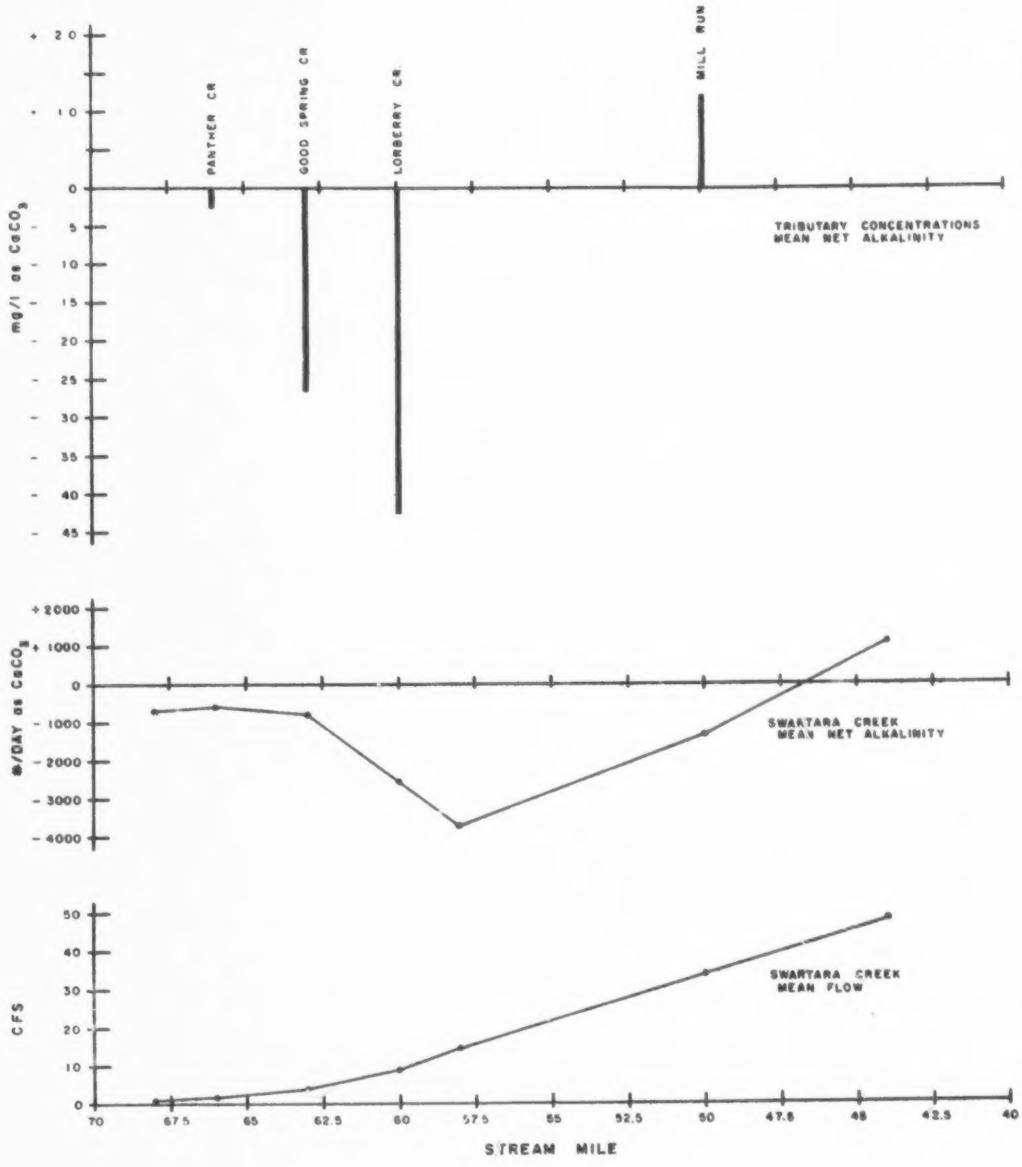
PROFILE OF FLOW, NET ALKALINITY OF MAHANTANGO CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

FIGURE 12



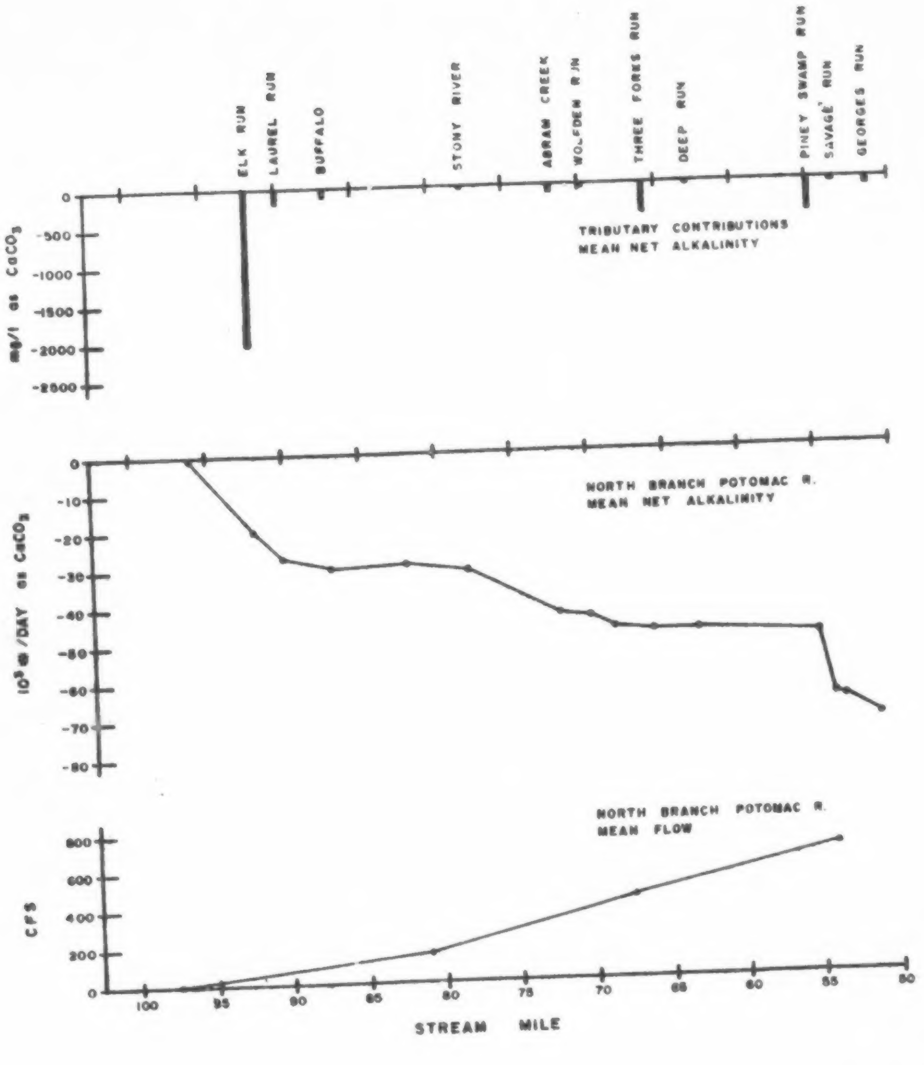
PROFILE OF FLOW, NET ALKALINITY OF WISCONISCO CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

FIGURE 13



PROFILE OF FLOW, NET ALKALINITY OF SWARTARA CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

FIGURE 14



PROFILE OF FLOW, NET ALKALINITY OF NORTH BRANCH POTOMAC RIVER
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

FIGURE 18